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MINE SURVEYING

BY

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PREFACE

In this book little is said about general surveying methods, it being assumed that the user is familiar with the ordinary methods. The general matter in Chapter I is introduced to establish a common ground for discussion and to save repetitions elsewhere.

The scheme of treatment of each division of the subject is to first give the principles and general methods of procedure such as a student or an engineer familiar with general surveying might need in taking up mine work, and then follow with examples showing variations in practice.

The methods used to overcome difficulties encountered at various places should be useful to practicing engineers, as guides in laying out programs of work for particular problems. They also show what may be expected and emphasize the importance of operations described in the general discussion.

Few of the common instruments are shown, as they may be obtained from any maker and are fully described in their catalogs. The special fittings are made by most manufacturers, although there are slight variations in their patterns. The choice of the types here illustrated was settled by the quality and instructive value of the cut that was available and with an attempt to be impartial to the various instrument makers.

Credit is given throughout the text to the author from whom material has been borrowed. The abstracts have been made so full that it will not be necessary to refer to the original documents, except as stated or where information outside of the surveying is wanted.

Edward B. Durham.

Berkeley, Cal.,
September, 1913.

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MINE SURVEYING

CHAPTER I

GENERAL SURVEYING METHODS

The principal instruments for all kinds of surveying are the transit and the level. The general methods of caring for, adjusting, and using them are described in all books on plane surveying. A brief review here will establish a common ground for further discussion and will give a chance to mention some of the short-cuts and methods that have developed in practice, whose description would be out of place in elementary works on surveying.

ADJUSTMENTS

The Adjusting Yard.—In mine work, the instruments get hard usage. They receive many knocks and jars in transportation, and they get both wet and dirty which necessitates frequent cleaning on the inside as well as on the out, consequently they need frequent readjustment. The testing of the adjustments is reduced to a matter of 15 or 20 minutes, for one man alone, by doing it in an adjusting yard, established near the office or in the vicinity of each mine if they are scattered, and the instruments are not returned to the office. Such a yard is shown in Fig. 1. A is the point where the instrument is to be set; it should be a permanent stake with a tack in its center. At approximately equal distances, say 200 ft. on each side, there should be set a point B and a scale C about 5 ft. higher than stake A. These should all be in a straight line, and are used to test the collimation of the transit. On the wall at a horizontal distance of 10 to 15 ft., a point D should be set, as high as can be seen with the transit, and a scale E set vertically below it, as low as possible, so that the vertical angle included between the two sights will be large, say 75°. These are used to test the horizontal axis of the transit. The points *B* and *D* are tacks driven in white areas, so as to distinguish them from other nails, and scales *C* and *E* are permanently fastened in a horizontal position and may be a white board graduated as shown in the corner of the figure. The rod *F* is graduated like a Philadelphia leveling rod, with marks that can be read from *A* with the instrument. This rod is used for adjusting the long level on transits and for dumpy levels. Its graduations should be numbered from a zero point that is on the same level as the top of stake *A*. The graduations, however, need only be drawn on the rod between the 4- and the 6-foot marks. This same rod or a similar one may be used for testing the stadia wires, in which case the tack in stake *A* should be set an accurate distance from *F*, say 300 ft. plus the instrument constant, so that the stadia wires will include a known distance on the rod when they are in adjustment. For this use it is not important where the zero of the rod is placed, but the graduations should cover sufficient space to be in the field of the instrument when the telescope is horizontal and the instrument is set anywhere from 4½ to 5½ ft. above the stake *A*.

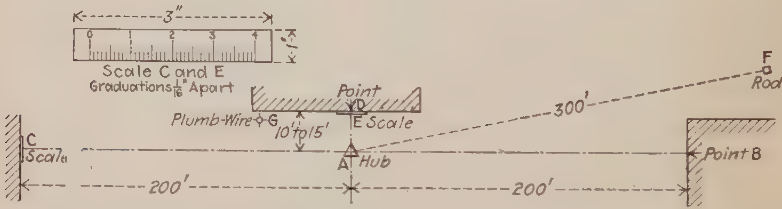

FIG. 1.—Plan of adjusting yard. Dimensions are only suggestive. Point *D* should give a vertical angle of 45° up and scale *E* should give 30° down.

Adjustments of the Transit.—The parts of the transit needing adjustment are:

1. Plate bubbles.
2. Vertical cross-wire.

3. Line of collimation.
4. Horizontal axis.
5. Long bubble.
6. Vertical circle.
7. Stadia wires.

The transit is set over stake *A* and leveled with the long bubble. It should be accurately set over the tack if the stadia is to be tested, otherwise its exact setting is not important.

1. The plate bubbles are brought to the center of their tubes by means of their adjusting screws, for the plates have been made level with the long bubble and hence the small bubbles should be in the center of their tubes. A reversal of the transit will show the sensitiveness or sluggishness of the small levels, but the bubbles should return to the center.

2. The vertical cross-wire is brought to the vertical, so that all parts of it will be in alignment when sighting on a plumb wire, hanging at *G*, or on a vertical line scribed on the building.

3. The line of collimation is adjusted by using point *B* and scale *C*. Sight on *B* with the telescope *normal*, clamp the vertical centers, plunge the telescope and read scale *C*; next sight on *B* with the telescope *reversed*, clamp the vertical centers, plunge the telescope, and read scale *C* again, then adjust the cross-wires until the readings on scale *C* are the same both times.

4. The horizontal axis is tested by using point *D* and scale *E*. Sight on *D* with the telescope *normal*, clamp the vertical centers and read scale *E*; repeat with the telescope *reversed*, and adjust the bearing of the axis until both readings of scale *E* agree.

Errors in collimation affect the accuracy of the test of the horizontal axis and *vice versa*, hence adjustments No. 2, No. 3, and No. 4 must be repeated alternately until all are correct. If there is reason to suspect that any one of these three adjustments is seriously out, that one should be corrected first.

5 and 6. The long bubble and the vertical circle are adjusted together. Two cases may occur, due to the design of the instrument. 1. When the vertical arc or its vernier are adjustable. Measure the height of the horizontal axis of the transit above

stake *A;* point the telescope at rod *F*, setting the horizontal wire on the graduation corresponding to the height of the instrument (the horizontal wire should have been left in the center of the field when adjusting the collimation), the telescope is now horizontal; adjust the level tube until the bubble is central, then adjust the vertical arc or its vernier so that the two zeros correspond. If the level tube is not adjustable, bring the bubble to the center by revolving the instrument, then move the horizontal wire so that it will fall on the proper mark on rod *F* and retest collimation as in the next case. 2. When the vertical circle or its vernier are not adjustable. Measure the height of the transit above stake *A*; bring the vertical circle to zero; sight on the rod *F* and move the horizontal wire until it falls on the graduation corresponding to the height of the instrument (this may affect the line of collimation, which should be retested), the line of sight is now horizontal; adjust the level tube to bring the bubble to its center.

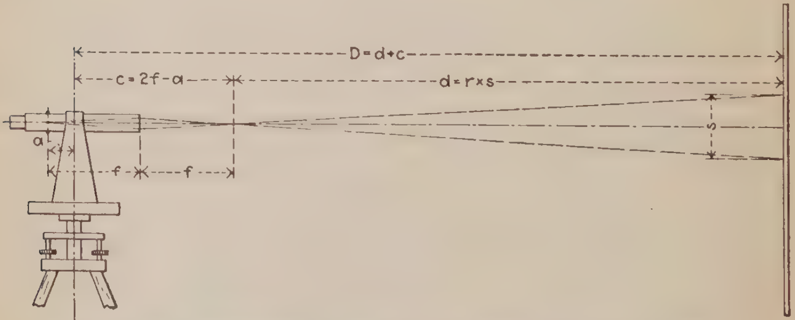

FIG. 2.—Stadia constants. Distance *f* is measured when objective is focused on an object 200 to 300 ft. away.

7. The stadia wires are tested on rod *F*. The distance *A* to *F* should equal the space on the rod included by wires multiplied by the ratio of the distance *d* to the reading *s*, plus the constant *c*, see Fig. 2. The constant *c* and the ratio, $\frac{d}{s}$, depend on the instru-

ment. The constant c is often stated on the instrument box by the maker or may be measured from the instrument by the method shown in the figure. The ratio, $r = \frac{d}{s}$, is usually 100, that is, 1 ft. on the rod corresponds to 100 ft. in distance. This method of adjustment makes all distances correspond to the formula: Distance = (ratio × reading) + constant. Sometimes the stadia wires are adjusted so as to include a space on the rod equal to the distance divided by the ratio, neglecting the constant, and the adjustment is made for a distance equal to the approximate mean of the distances to be measured. The results obtained in using the stadia when the wires are adjusted in this manner are not as accurate as when the constant is taken into account.

Adjustments of the Y-level.—The adjustments of this instrument can all be made by one man in a few moments with the instrument set up in any shady spot, using the ordinary methods given in any text-book on surveying. The adjustments are:

1. Optical axis is made central with the telescope.
2. Bubble tube is made parallel with the optical axis and the telescope.
3. Telescope and optical axis are made normal to the vertical axis.

Adjustments of the Dumpy Level.—The testing of this instrument can be expedited by using the fixed points in the adjusting yard. The parts needing adjustment are:

1. Long bubble.
2. Horizontal wire.
3. Collimation of the horizontal wire.

1. Adjust the long bubble until it stays in the center of its tube for all positions of the telescope when revolved about its vertical axis. This also makes the main spindle vertical.

2. Set the horizontal wire level by sighting on a distant object and swinging the telescope, so that the object crosses the field. It should appear to travel along the wire.

3. Adjust the collimation of the horizontal wire by moving it vertically, so that the same reading will be obtained by sighting

on each of a row of level pegs, set at different distances from the instrument. This adjustment may be made in the adjusting yard, by a method similar to No. 5 and No. 6 for the transit, by setting over the hub, *A*, and sighting on a point at the same height at *F*.

CARE AND CLEANING OF TRANSITS

The exterior of the transit often gets very dirty and wet and should be wiped dry at the close of each day's work, using a clean cloth or cotton waste, as water left standing on it may work inside and corrode the bearings, cloud the lenses, or discolor the verniers. This wiping also gives an opportunity for an inspection of the instrument.

When working in a very wet place, the transit should be protected from being flooded with water by covering the compass box and vernier when not observing them with a rag, which will act as an absorbent for the water and prevent it from getting inside, and if it must be left standing under falling water, it should be covered with a waterproof hood. It should also be wiped between set-ups to get rid of the excess water on it. This care of the transit is especially important where the water is corrosive or muddy.

Besides getting water and dirt on them, mine instruments also become smoked from the lights and candle grease or oil drops on them. These can be removed with rags dampened with denatured alcohol, benzine, or kerosene, which soften the smoky grease, dry quickly and do not corrode. They should not be applied in such quantities as to flush the dirt from the outside into the interior or into the joints. Alcohol is especially valuable as a cleanser of instruments as it softens grease and also combines with water, thus drying as well as cleaning.

Dirty lenses should be dusted with a camel's hair brush and if smoked or greasy they may be washed with alcohol. When clean they should be polished with a soft linen handkerchief or soft tissue paper. A dirty lens must be cleaned before the polishing as the grit on it will scratch it, even if the cloth used is clean.

The ring holding the lens may be unscrewed so as to allow the inside surface to be wiped, but the various layers of the lens should not be taken apart as there is little danger of dirt getting in between them and it is almost impossible to get the various layers back again in their proper position. If alcohol is used to clean the outside of a lens, care must be used that no surplus alcohol works in between the layers of the lens as it may carry dirt with it and leave a stain.

Dampness in the telescope may sometimes be dried out by keeping the instrument in a warm place for a few hours. If there is water in the telescope, it will be necessary to remove both the eye piece and the objective, in order to dry it out. Whenever the lenses are unscrewed, especially the objective, the optical axis of the instrument is moved and the adjustment of the collimation must be tested.

Water will sometimes get into the *compass box*, or on the horizontal verniers, from water dripping on the instrument. The compass glass can be removed by unscrewing the ring, or springing out the wire that holds it in place, and the interior can be wiped out. The glass over the vernier can sometimes be taken off by removing a few small screws, thus giving access to it for wiping or polishing, but usually it is necessary to take the instrument apart.

The interior of most transits is reached by removing a single screw in the bottom of the vertical spindle, which allows the centers to be separated, if the clamps are also loosened. The interior can then be cleaned and access is gained to the connections holding the minor parts of the instrument to the main casting. Ordinarily these connections should not be touched except by an instrument maker, for if once moved it is difficult to replace them in their correct position.

The centers should be wiped clean with a soft rag and then reoiled with a little "nut oil." This oil has a good body, but does not thicken with cold. It is used for clocks and watches and is sometimes called "watch oil."

The silver plates should be wiped to remove smoke and grit, but it should be done very carefully so as not to scartch them or injure the graduations. If they are tarnished, they should be polished with the softest thing that will do the work. An old linen or cotton cloth with "Electro-silicon" silver polish is good. The tarnishing of the plates is due principally to sulphur in the air or in the water, and is not apt to occur very often.

Other bearings, like those for the horizontal axis, may be oiled with a very little nut oil. Care should be used that the various axes are kept dry where the clamps seize them, so as not to reduce their holding power.

Open screws should not be oiled as the oil will collect dirt and the screws will move hard. They should be lubricated with graphite, which will not collect dirt. The lead of a very soft pencil is good.

The clamps on the wooden tripod legs must be loosened after use, for the wood will swell if it absorbs moisture and bind the legs. In severe cases, the swelling may break the clamps themselves.[1]

In packing instruments for shipment, the space between the instrument and its box should be packed full of soft paper to insure against anything working loose and rattling around, and then the box should be packed in a larger packing case, and the space between the two filled with soft packing. The packing cases should have handles so arranged as to make it convenient to handle them and so that they will naturally be kept right side up. Heller & Brightly point out that an instrument so packed will be carried by the express companies at the usual merchandise rate, while an instrument shipped without an outside packing case is charged for at three times that rate.

REPAIRS

The Transit.—Any surveyor may have to make minor repairs to his instruments and often must make important temporary repairs in order to continue the work. Broken tripod legs can be repaired with splints fastened with string or wire until new ones can be made by a carpenter. Broken screws can be replaced by wooden pegs screwed into the holes; they will hold for a while. Broken parts, such as a tangent screw, can be soldered. Bent parts may be repaired by removing them from the instrument, laying them on a suitable surface, placing a block on them and then straightening them by light hammer blows on the block.

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[1] The structure of the various makes of instruments and articles on their care are given in the trade publications of various makers, but especially in those of W. & L. E. Gurley, Troy, N. Y., C. L. Berger & Sons, Boston, Mass., and Heller & Brightly, Philadelphia, Pa.

Duplicates of such parts as are liable to injury should be kept on hand together with the tools for replacing them. The parts of transits that are most liable to breakage are, the top of the compass, the level vials, the tripod clamps and the cross-hairs. A new glass can be put in the compass box by taking off the wire ring that holds the glass. New clamps can be put on the tripod legs with the aid of a screw driver. A broken level vial and the old cement can be removed from the metal tube, a new vial inserted, wedged in place with a piece of paper, and fastened with plaster of Paris. Care must be taken that the convex or marked side of the vial is on the upper side.

Broken cross-wires may be replaced by spider webs by using care and patience.[1] The materials required are a pair of dividers or a piece of wire or a stick or card that can be cut to give a V shape, shellac varnish (on a temporary job, mucilage can be used), a little bee's wax, a couple of small pointed sticks, and some spider's webs or a spider's cocoon. In putting in the new hairs, the eye piece slide is unscrewed without disturbing the objective. Two of the capstan headed screws that hold the ring carrying the cross-wires are loosened and the ring is rotated on the remaining two as pivots, until one of the pointed sticks can be inserted through the telescope tube and screwed into one of the screw holes; then using this for a handle, the other screws are removed and the ring is taken out. All the old shellac is cleaned from the lines on the ring, and it is placed on the table with the lines upward. An inch or two of the web is now pulled out of the cocoon or secured from a clean web; it is held by the bits of wax on the ends of the dividers, or by shellac to the forked stick. It is examined with a magnifying glass to see that it is not ragged, is moistened with the breath and as it slackens, the dividers are spread so as to stretch it, but not over $\frac{1}{16}$ in. from its dry length. The web, still on its holder, is placed over the two lines on the ring, using a magnifying glass to insure accuracy. A small drop of shellac is now put on each end of the web, about $\frac{1}{16}$ in. back from the inner edge of the ring, and left to harden. After all the webs are set, the ring is replaced by reversing the operations used in removing it. The web should be on the side of the ring nearest the eye piece. If possible, all work should be done from the eye end, as the removal of the objective is apt to disturb the adjustment of the objective slide, which adjustment is made by the maker and troublesome for the surveyor to remake.

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[1] E. M. Douglas, *Eng. News*, Jan. 25, 1906, Vol. LV, p. 89.

Steel Tapes.—These are frequently broken. The narrow ones can be mended by soldering a brass sleeve over the break. The ends of the tape are cleaned, dipped in an acid soldering solution, and coated with melted solder. The brass sleeves are similarly coated on the inside and then hammered firmly over the break, so as to hold the tape at the correct length. The sleeve is then heated until the solder melts, and then allowed to cool, when the joint is made.

Emergency repairs may be made in the field with a "Little Giant"[1] tape splice. The ends of a broken tape are inserted in the metal sleeve, adjusted to butt together as can be seen through a sight hole, and then two screws are turned down with a knife so as to grip the ends of the tape.

The wide tapes can be repaired by cutting out $\frac{1}{2}$ in. or more at the break so as to square the ends, and then riveting in a patch, made of a scrap of similar tape of such length as to preserve the original length of the main tape. The ends of the tape and the splice are annealed by pressing them on a piece of hot iron until they turn dark blue. Two small holes are punched near each end, on a line square across the tape with a punch made from a file, darning needle or similar small steel. The holes in the tape and those in the splice should match so that the two parts of the tape will be in line. Small brass rivets are inserted in the holes and riveted over. Heavy pins or fine brass escutcheon nails can be cut off short and used as rivets.

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[1] Sold by dealers in surveying supplies for 35 cents each.

Special punches, Fig. 3, are made with which holes $\frac{1}{16}$ in. in diameter can be made in the tape, in which brass eyelets are inserted and then riveted by pressure applied by knobs on the punching tool.

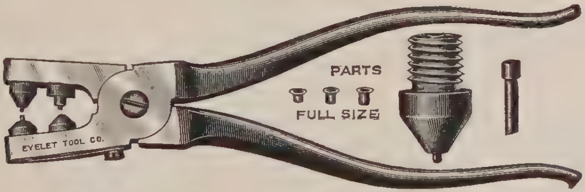


Fig. 3.—Punch and set for repairing wide tapes. Made by Eyelet Tool Co., Boston, Mass.

SURVEYING METHODS

Reading of Horizontal Angles.—The reading of the horizontal angles may be done in five different ways. The one that is to be used in any particular case depends on the use to be made of the information and the accuracy required. The usual methods of reading the angles are:

1. By direct reading.
2. By deflection.
3. By bearing.
4. By azimuth.
5. By repetition.

These are illustrated in Fig. 4 where the same angle is measured by each of the five methods.

1. *By Direct Reading.*—In this method, the telescope is set on the back target with the plates at zero using the lower clamp; then without plunging, the telescope is turned to the forward target using the upper clamp, and the angle is read. The instrument should be graduated from 0° around to 360°, prefer-

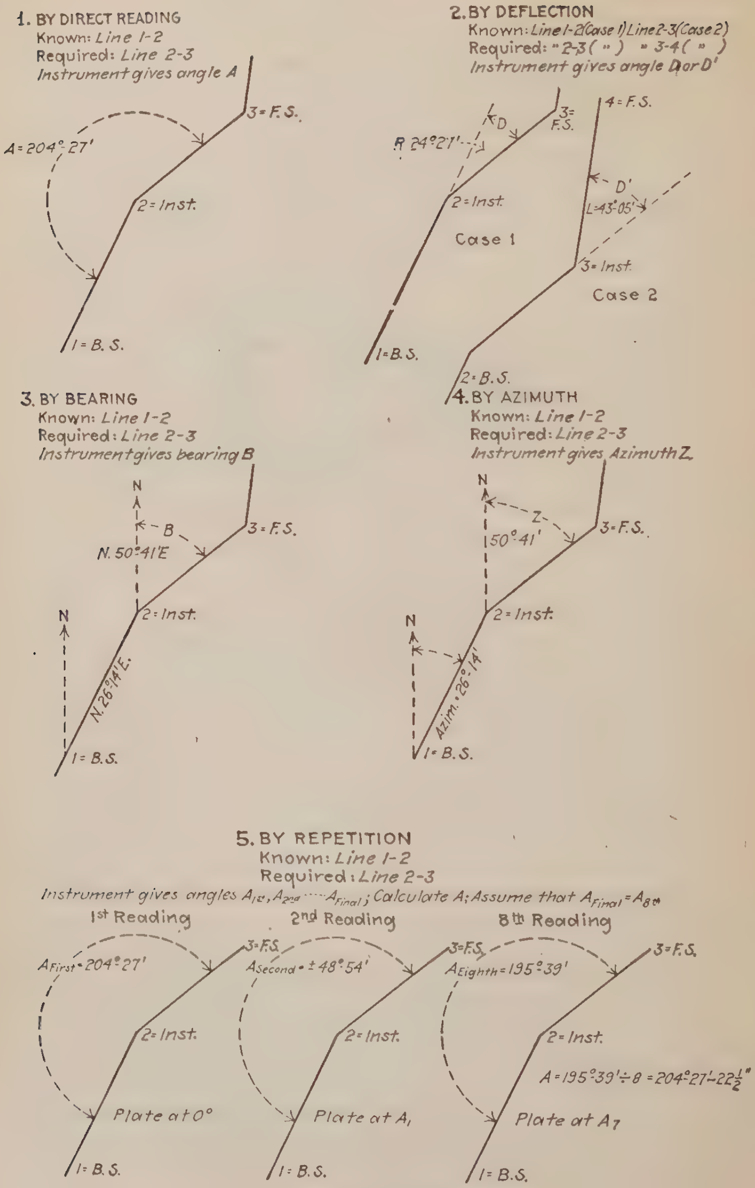


FIG. 4.—Angle measurement.

ably to the right, so that angles are measured in the clockwise direction.

The direct reading is the most natural way to measure the angle; it is used for numerous purposes, but it gives only a single reading without any check except by repeating it. If the angle is repeated with the telescope reversed, gross errors of adjustment may be detected, but other errors may not be suspected.

2. *By Deflection.*—In this method, the telescope is set on the back target with the plates at zero, using the lower clamps, then the telescope is plunged, and is turned to the forward target, using the upper clamp, and the vernier is read. The instrument should be graduated from 0° in both directions to 180° at the opposite end of that diameter. The angle read is the angle of deflection or deviation of the forward course to the right or left from the direction of the last one prolonged.

This method is used in railroad surveys as the deflection angle is convenient for curve calculations. It gives only one reading of the angle and requires that the record of the angles be prefixed by the letter *R* or *L*, to denote the direction of the deflection. It can be checked by repeating the angle preferably with the telescope in the reversed position on the back sight.

3. *By Bearing.*—In this method, the telescope is reversed and set on the back target with the plates set at the bearing of the last course as read from the previous station, using the lower clamp; then the telescope is plunged and is turned to the forward target using the upper clamp, and the bearing of the forward course is read from the plates. At each station when the back sight is taken the north and south line on the plates is thereby oriented parallel to the original meridian. The bearings are in the correct quadrant only when taken with the telescope in the normal position. The instrument should be graduated in quadrants, like a compass, with a zero at both the north and the south points and 90° at both the east and the west points.

This method gives the bearing of each course as in compass surveying, except that the bearings are referred to the same meridian as used for the first course, whether that was a magnetic, a true, or only an assumed meridian. It is useful in running land surveys as the instrument readings are the same as the descriptions and need no reduction or translation. Care has to be taken to note the quadrant in which the course lies. There is practically no means of checking the instrumental work as the plates are left clamped at the bearing of the forward course when moving, and are used in this position when taking the backsight and orienting the instrument at the next station.

4. *By Azimuth.*—In this method, the telescope is reversed and set on the back target with the plates set on the azimuth of the last course as read from the previous station, using the lower clamp, then the telescope is plunged, and is turned to the forward target using the upper clamp, and the azimuth of the forward course is read from the plates. The instrument should be graduated from 0° to 360° to the right or clockwise. After taking the foresight the plates are left clamped and are used in this position without resetting, unless they have slipped, in taking the backsight at the next station.

This method is a rapid one for traverse work, especially when combined with stadia measurements for the distances. The instrument retains the fractions of the minutes which are too small to be read; this often gives a traverse whose angles close exactly. With the same care in doing the instrument work and in the measurement of the distances, the results by this method are more accurate than by any one of the preceding ones but not so accurate as by the repetition method. There is no check on the angle readings as they are taken only once, and if repeated the plates have to be moved and the accumulation of the fractions of the minutes is lost.

5. *By Repetition.*—In this method, the telescope in the normal position is set on the back target with plates set at zero using the lower clamp, then the telescope without plunging is turned to the forward target using the upper clamp, and the angle is read from the plates and recorded. This is the first reading and the method so far is the same as that by Direct Reading. Then with-

out resetting the plates or plunging the telescope a second reading is taken consisting of a sight on the back target using the lower clamp, and a sight on the forward target using the upper clamp. The plates will then show twice the original angle, but this need not be read. The angle is repeated, as on the second reading, as many times as desired. The vernier is read at the end of the last measurement and this angle divided by the number of repetitions gives the angle between courses. This last angle should agree closely with the first one of the set, and the comparison of the two will detect errors in the work. By taking the first half of each set with the telescope in one position and the second half with it in the reversed position, many instrumental errors are balanced and so eliminated. The instrument should be graduated from 0° to 360° to the right.

This method gives the greatest degree of exactness that is possible with the transit, especially when the sets consist of about eight repetitions each and several sets are taken and their results are averaged. The method is always used for triangulation work and should be used on other important work. The author recommends for traverse work that a set of four repetitions be used, two readings being taken with the telescope normal and two being taken with it reversed. This short repetition set uses about the same amount of time as required to read an angle once by any other method and then to reset the vernier and read the angle a second time as a check; affords a greater degree of accuracy as a fourth of the last reading is used as the working angle and gives the angle to the nearest 15″ if the vernier is read to minutes; and detects errors in vernier readings when four times the first angle is compared with the last one. In the other methods when a single angle is reread, the same point on the circle is observed the second time and may be involuntarily read and recorded in the same erroneous way both times.

Magnetic Bearings.—Compass readings are too inaccurate for important surveys, but the recording of the magnetic bearings at each station of a transit survey affords an excellent check against gross errors in the angle reading. If the magnetic bearings are taken both on the backsight and on the foresight, the difference between them will give the angle at that station independent of any local attraction that may be present, see Fig. 5. The bearings should be noted to the nearest $\frac{1}{4}$°.

Magnetic bearings should always be taken where the transit angles are read only once as in any of the first four methods previously described, and the author recommends that they be taken even when the angles are read by repetition. In the latter case, an error may not occur very often, but if a discrepancy between the first and last angle of some set is not detected until the notes reach the office or some traverse fails to close by a large amount, then the magnetic bearings may serve to locate the error so that only a small amount of instrumental work will have to be repeated, and in some cases the magnetic bearings may show the nature of the error and which figures are wrong and which are right, so that the correction can be made in the office.

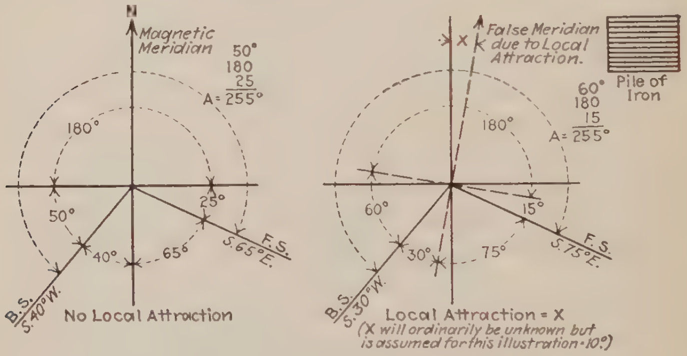
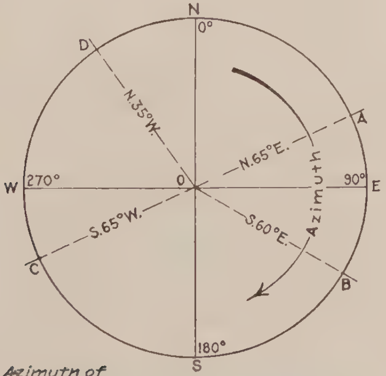


FIG. 5.—Neutralizing local attraction.

Magnetic readings have been useful in detecting and often correcting such errors in readings as mistakes of 1° or 10°, forgetting the 30′ in angles containing more than one-half of a degree where the vernier was graduated to 30′, errors of 180° due to reading the wrong vernier on the first or last reading of the set, or reading the wrong figures occasionally when a transit has two sets of figures on the plates.

Azimuth.—The azimuth of a line is the angle the line makes with the meridian, measured from the *north* around to the *right*, *i.e.*, clockwise. This makes the azimuth of a line whose bearing is north equal to 0°, east equal to 90°, south equal to 180°, and west equal to 270°, see Fig. 6. This is the author's definition and is used throughout this work. It is a convenient form and is used by many engineers, and makes the azimuth correspond to the figures on the transit plates.[1]



Azimuth of
OA = 65°, OB = 120°, OC = 245°, OD = 325°

FIG. 6.—Definition of azimuth.

In a survey where the angles between courses have been measured to the right, *the azimuth of a course equals the azimuth of the previous course plus the angle between the courses and minus* 180°, see Fig. 7. When the sum of the previous azimuths and the angle are less than 180° it is necessary to add 360° before subtracting; this is the same as *adding* 180° which is the method used in practice, but it does not alter the rule. Where the deflection angles are read, the azimuth of a course is the azimuth of the last course plus or minus the deflection angle of the forward course. The angle is added when the deflection is to the right and subtracted when it is to the left.

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[1] There are some surveyors and writers, notably among whom is Johnson, who measure the azimuths from the south as zero turning to the right. This is also the custom in astronomical work. The surveyor, if he wishes, can use this last definition of azimuth without affecting his work, provided he uses it in the same way throughout his entire survey.

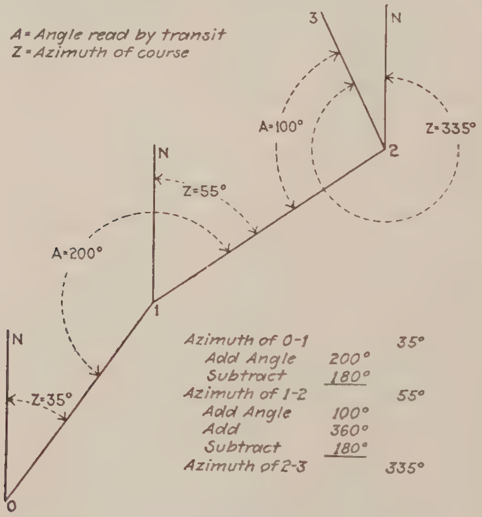

FIG. 7.—The calculation of azimuths.

Reading of Vertical Angles.—Vertical angles are used in connection with inclined tape measurements of distances to determine the horizontal and vertical distances between the points at the ends of the taping.

On surface, the vertical angles are usually small and a vertical arc is sufficient, but for underground work, it is advisable to have a full vertical circle so that large vertical angles can be read; that the telescope can be plunged without having to pay attention to the vertical arc, and also that the angles can be read with the telescope either normal or reversed.

Vertical angles are measured directly, that is, the angle above or below the horizontal is measured only once. It can be checked by repeating the observation, which is preferably done with the telescope reversed. In some cases, it is possible to reread the vertical angle from the other end of the inclined line as an additional check, when the instrument is set up at the further point. The ordinary reading of vertical angles is satisfactory for reducing the inclined distance to a horizontal one, when the inclination is not large, but special care must be used, in determining the angle, first, where the incline is over 30° and the vertical angles are used to reduce the tapings to the horizontal, and second, where the elevations are determined by the tapings together with the vertical angles, as in both these cases an error in the angle has a great effect on the result.

The measurement of the vertical angles is the least accurate part of the work done by the transit, and when most carefully done it is less exact than the single reading of a horizontal angle, hence special attention must be given to checking the vertical angles by rereading them. Where possible, the elevations should be obtained by leveling and the use of vertical angles should be limited to reducing the tapings to the horizontal. In mine work, where the vertical distances are of great importance, it is often impossible to obtain them in any way except by calculating the vertical height from the tapings by means of the vertical angles. This necessity of placing such important work on the weakest part of the transit is unfortunate. The addition to the transit of means for reading the vertical angles by repetition would complicate the instrument and would not remove the difficulties since part of the responsibility for the accuracy of the vertical heights depends on the tapings, and the latter are ordinarily less accurate than the angle readings.

Keeping of Traverse Notes.—The particular notes to be kept depend on the nature of the survey. For traverse work and in collecting details, the notes should begin at the bottom of the page and work up, then holding the book in the hand, the order of the notes and the directions on the sketch are in the same position as they are on the ground.

The descriptions of points on a traverse, with their identifying marks and descriptions of their witnesses should be given for permanent stations, so that they can be found in the field by other parties and their identity positively determined.

It is convenient to provide the field book with an oil-cloth cover, which can be slipped onto the book when it is used in the field and which can be removed when the book is in the office. This keeps the cover clean, so that it can be marked on the back for filing and so that a dirty book does not have to be used on the drafting table. This is especially important with mine note books.

Leveling.—The methods of performing the field work in leveling are practically fixed, and are familiar to all surveyors. For most surveys, the reading of the rod to hundredths of a foot will give sufficiently accurate results, and the work may be done with a dumpy level and a Philadelphia rod. The dumpy level is more compact and cheaper than a Y-level; the adjustments are not as quickly made as on a Y-level, but as they do not have to be made very often; this is not a serious objection. The dumpy level will give about as accurate results as a Y-level. The Philadelphia rod is graduated to hundredths of a foot; the graduations are coarse enough for the man at the instrument to read them directly, on sights not over 200 or 300 ft. long, and the target may be used for the longer sights. Such rods are often spoken of as "self reading rods." For refined leveling, the readings are made to thousandths of a foot, using a Y-level with a long telescope, and a New York rod, and the target is set for every sight and its vernier is read by the rodman. An excellent check can be obtained on important lines of levels, without rerunning them, by using the method of double rodding.

A rod level is valuable on exact work as it enables the rodman to hold the rod exactly plumb and saves the time used in waving it to get the minimum reading. On ordinary work, where the rod is read to $\frac{1}{100}$ ft. by the instrumentman, the rod level is also useful as it permits a less expert rodman to be used and still ensures the rod being held properly. The best pattern is shown in Fig. 8; this level is held on the rod when in use by a rubber band.

The level notes should be taken in the form shown in Fig. 9. In this system, the sights of the main line are placed in the columns headed *B.S.* (backsight) and *F.S.* (foresight), then by simple addition and subtraction the arithmetical work of the main line can be verified as often as desired, as shown in the figure. The sights to other points than turning points are called rod sights, *R.S.*, and their elevations are placed in the last column, headed *El. of Pt.* (elevations of points). Some surveyors place all the sights in one column, but then the arithmetic can only be checked by refiguring it or by taking off a list of the instrument sights and proving them on a separate sheet.

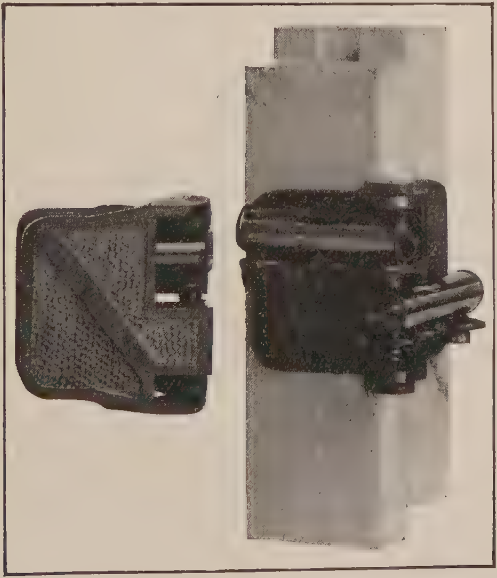

Fig. 8.—Rod level. Made by W. & L. E. Gurley, Troy, N. Y.

In the above, the remarks are placed on the right-hand page.

The notes can be condensed by placing the elevation of the turning points in the column with the elevations of points, and where the remarks are very brief, as in R. R. leveling, the station numbers can be placed in the last column thus getting all of the notes on one page and enabling both pages of the note book to be used for level notes.

B.S.	H.I.	F.S.	T.P.	R.S.	El.of Pt.	Remarks
			200.00			B. M. White Oak Stake 115 ft. R. of line
4.683	204.683			2.1	202.6	Sta. 0
				3.4	201.3	Sta. 1
				5.2	199.5	Sta. 1+50
		9.214	195.469			
1.791	197.260			3.7	193.6	Sta. 2
				7.0	190.3	Sta. 2+25 Brook 5 ft. wide.
				3.1	194.2	Sta. 2+50
				0.5	196.8	Sta. 3
		0.436	196.824			
11.750	208.574					
		0.979	207.595			
11.933	219.528			3.5	216.0	Sta. 3+90
				2.6	216.9	Sta. 4
				2.075	217.453	B. M. on Maple, 78 ft. L. of line
				1.7	217.8	Sta. 5
				0.9	218.6	Sta. 6
		0.732	218.796			
9.005	227.801			6.2	221.6	Sta. 7
39.162		11.361				
200. =	B. M. add					
239.162						
11.361 =	F. S. subtract					
227.801 checks last H. I.						

FIG. 9.—Form for level notes.[1]

Measurement of Distances.—There are three methods of measuring distances that are available for surveying:

1. By chaining.
2. By stadia reading.
3. By taping.

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[1] Rearranged from Searle's "Field Engineering."

Chains are applicable to surface work only, they have a low degree of accuracy and are out of date except for rough work.

The stadia method is valuable for rapid surface work, it is nearly as accurate as ordinary taping especially in rough country, but is not recognized for U. S. Land or Mineral Surveys, and cannot be used underground.

Taping has the widest application. It may be done with such accuracy as to make it suitable for the base-line measurements of triangulation surveys, or it may be done with so little care that it is as rough as chaining. In general, the measurement of the distances in ordinary surveying is less accurate than the accompanying angle measurements. The operation of taping is simple in principle; the accuracy depends almost entirely on the skill with which it is done, and constant vigilence must be used to maintain the grade of the work.

Methods of Taping.—There are two methods used in careful taping:

1. Short measurements between stakes.
2. Long measurements with free spans.

The system of *measuring between stakes* consists of setting a row of stakes in line by the transit, placing a fine mark on each and measuring the distances between the marks. If the stakes are all on the same level, the horizontal distance is the sum of the distances between the stakes. Where the stakes are on different levels, two methods are in vogue. First, the distances are measured horizontally with one end of the tape held on the up-hill stake and the other held at the line of a plumb-bob over the down-hill stake. For medium grade work, the plumb-line is held by one of the chainmen, who also decides when the bob is over the mark and the level of the tape is determined by the eye. For careful work, the bob is suspended over the point from a staff and the tape is leveled with a hand level. Second, the distances are measured from stake to stake on the incline, the elevation of each stake is determined with a Y-level and from the hypothenuse as taped and the vertical distance as found by the level, the horizontal distance between each pair of stakes is calculated.

For distances of 100 ft. and under, the sag is often neglected with a light tape. It is better to determine the tensions for 25-, 50-, 75-, and 100-foot spans at which the tape is of the standard length, that is, the tension at which the stretch equals the shortening due to the sag; then the measurements are made at the tension corresponding to the distance, the tension being determined by a spring balance, and no corrections are needed.

The method of *long measurements* consists of stretching the tape at a known tension in a single free span from one station to the next, measuring the inclination of the chord, correcting the inclined taped distance for sag and reducing it to the horizontal by means of the measured inclination. This is the only method that can be used where the vertical heights are determined from the tapings and the vertical angles, and is the method that is most applicable in mine surveying.

On distances over 100 ft., the shortening of the tape due to sag cannot be overcome by elongating the tape as the required tension increases rapidly with an increase in the length of the span and soon becomes too great to be practical.

The usual practice is to apply a uniform tension, of say 20 lb., as indicated by a small spring balance, in making the measurements. A table of the catenary corrections for spans above 100 ft. and increasing by 10-foot intervals, can be calculated for the particular tape and tension adopted, and this correction can be subtracted from the taped measurement to get the corrected taped distance.

The *temperature* at which a tape measurement is made, is noted in the case of base-line work, and the proper correction is applied, but it can usually be neglected in traverse work.

Calculations.—The practice should be established in every office of making all calculations in "Scratch Books." The pages should be dated, a heading should be given showing to what the work applies, and enough explanatory notes should be made with the figures to explain the computations and to indicate what conclusion has been reached. An orderly method of procedure should be acquired but no great attention need be given to appearances, provided enough care has been used to make the work legible. Erroneous or superseded work should be merely cancelled and not destroyed as it may be wanted again.

The final results of calculation may be transferred to record sheets or books, or be plotted on maps or drawings.

Rough calculations of surveys may be made with a "trigonometer," which is a cheap device for solving right-angle triangles by mechanical methods; with a slide rule, or with traverse tables made out to ¼ degrees. Each of these has its limitations but each is excellent for work within its own field.

Traverse calculations require exact methods. The necessary accuracy can be obtained by using tables of either natural or logarithmic trigonometric functions, or large traverse tables.

The tables of natural functions should give the values for every minute, carried to four decimals. It is laborious to multiply out the calculations and the use of natural functions should be limited to the few calculations that are required in the field and for which it would not pay to carry the more bulky tables.

The use of logarithmic functions is rapid and well adapted to office work. The tables should give the logarithms of numbers of five figures and the logarithmic functions for every minute, with the mantissas of the logarithms carried to six decimals.[1]

Large traverse tables are the most rapid and the least tiring to use for traverse calculations. One calculated by R. G. Gurden ("Traverse Tables," 9½ by 14 in., 270 pages, $7.50, Chas. Griffin & Co., London) gives the products of the sines and cosines of angles varying by one minute into all distances from 1 to 100. Both products for any angle and all distances are on one page, so the book is only opened once for any angle:

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[1] These specifications are met by Dr. Bruhns' "Manual of Logarithms," $2.50, and by many other of the standard tables.

Plotting.—This may be done by any one of three methods, in surveying:

1. By angles and distances.
2. By azimuths or bearings and distances.
3. By coordinates.

The first two are not applicable to traverse work as the errors of plotting are cumulative. They are useful for minor surveys and in plotting details on a survey controlled by a traverse.

The last method locates every traverse point independently, and hence an error at one point can be detected by checking the work and be remedied without affecting the balance of the map.

CHAPTER II

EQUIPMENT FOR UNDERGROUND SURVEYING

INSTRUMENTS

Transits.—Underground surveys can be made with any instrument that is in fair condition, by improvising a few details, but instruments that are especially made for the purpose help to expedite the work and make it easier. Transits of the "Light Mountain or Mining" type, having horizontal circles, from 5½ to 5¾ in. in diameter, and weighing from 10 to 12 lb., are preferable to the larger transits ordinarily used on surface, and which have plates from 6 to 6½ in. in diameter, and weigh from 14 to 16 lb. The smaller transits are large enough to do good work, they are strongly built, and the reduction in size makes them lighter and allows them to be placed in more compact carrying cases.

The transit, of whatever type is chosen, should have: first, long vertical spindles for its main bearings, as are used in the best instruments; second, a shifting head for centering the instrument over the station points or for the more difficult work of setting *under* a station point in underground passages; third, a level on the telescope and a full vertical circle so vertical angles can be read with the telescope either normal or reversed; fourth, the main vernier for the horizontal plates not over 45° to one side of the eye end of the telescope so it can be read without obliging the transit man to leave his standing place; and fifth, the screw for the lower clamp fitted with a head of a different shape from that on the upper clamp, so that they can be distinguished by the touch in the dark. The above features are often included in a transit intended for surface work. The mine transit should have the following fittings which are unusual for surface instruments, namely, a carrying box with shoulder straps, a reflector for illuminating the cross-wires, a prism eye piece, a plumb-bob with an interior reel, and a tripod with three extension legs.

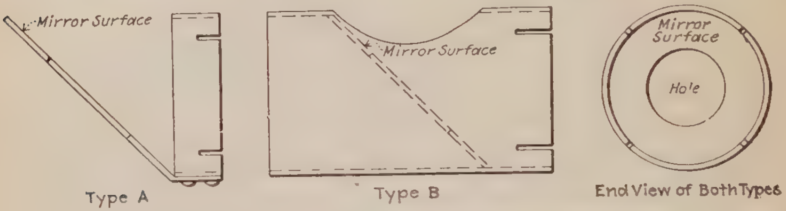

FIG. 10.—Reflectors for illuminating the cross-wires.

The *carrying box* should hold the instrument and all its fittings. It should be so arranged that they can be quickly slipped into place and securely held when the box is closed, thus allowing it to be moved in safety to and from the district to be surveyed or from one station to the next. The box should be provided with carrying straps like a knapsack, so it can be slung from a man's back for transportation in rough places, up and down ladder, etc. It is well if the box has a sole-leather case so that the sharp corners do not prod the man who is carrying it, The bottom of the case should be fitted with two pieces of steam hose, about 1 in. inside diameter, on which the box can stand. They should run across the box and be placed near each end of the bottom so as to give as large a base as possible. They can be fastened to a wooden box by screws through the side of the hose next to the box, or if the carrying straps extend under the box the hose can be strung on these.

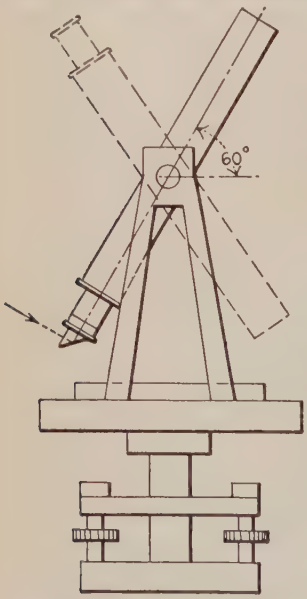

FIG. 11.—Use of prism eye piece.

The *reflector* for illuminating the cross-wires consists of a ring that fits the objective end of the telescope the same as a sun shade, and which supports a diaphragm at about 45°. This diaphragm is silvered on the inner surface and reflects light from a lamp or candle, held to one side, into the objective making the cross-wires visible. The diaphragm is pierced with a hole at its center so as not to interfere with the line of sight. There are two patterns on the market, Fig. 10. Both are satisfactory. One can make a good reflector like type *A*, out of tin, or in an emergency a fair one can be made of a card and be fastened to the collar of the telescope with a rubber band. For an occasional sight in the dark the wires can be illuminated by "flashing" a light across the telescope axis and a few inches in front of the objective.

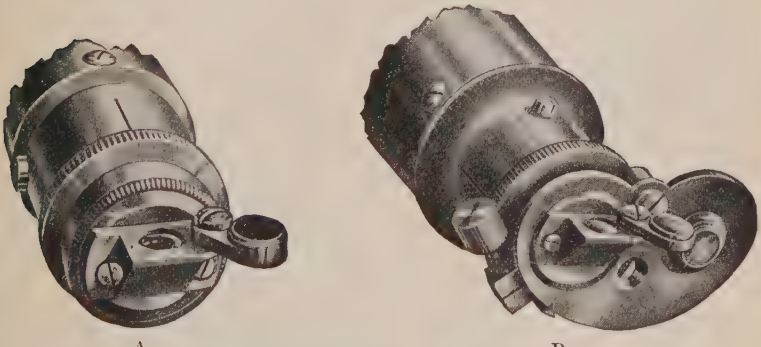
A B

Fig. 12.—Prism eye pieces. Made by Buff & Buff Mfg. Co., Boston, Mass.

The *prism eye piece* is useful for steep upward sights and for observations on the sun. In mine work an upward sight is occasionally required where the eye piece comes near or over the plates of the transit and it is impossible to look up the telescope with a plain eye piece as is shown in Fig. 11. Two common forms of prism eye pieces are illustrated in Fig. 12. The opening is provided with a colored glass window that can be used when sighting at the sun and moved to one side at other times. Form *A* is screwed on to the eye tube in place of the ordinary straight eye piece when a steep sight is to be taken. The improved form, *B*, can be placed permanently on the eye tube and allows any opening to be brought into use by simply rotating the heart-shaped plate with its attachments.

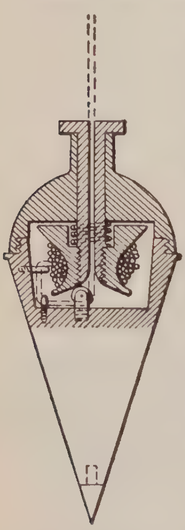
FIG. 13.—Adjustable or reel plumb-bob.

The *reel plumb-bob*, Fig. 13, is a great help in setting up the transit as it allows the length of the bob string to be adjusted quickly. For setting under a point this is a great help and when the point is only a short distance above the instrument it is almost essential in order to get rid of the surplus string.

The *extension tripod* is necessary in underground surveying as the ground is so rough that the set-ups are often peculiar and every leg has to be of a different length, or all the legs must be short for a low set-up. Extension tripods are convenient to carry and to stow away, when closed, during transportation in mine cars, etc.

Signals.—For underground surveying, the signals must either contain a light or be illuminated by a hand lamp or by a candle.

For a great deal of work, the ordinary plumb-bob hung from a station in the roof, or an overhead timber, makes a useful signal. In order to see it in the dark, a piece of white material is held behind it, and a light is held in front of this background, and to one side of the bob. This makes the object appear to the instrument man as a black silhouette on a white ground. For short distances, the sight can be taken on the string, and for long sights or for those in a hazy atmosphere the white background may be held behind the bob thus giving a larger object at which to sight. On short sights the white ground may reflect enough light to illuminate the cross-wires in the transit without using the reflector on the telescope. The large white surface is a help in finding the signal with the telescope.

When the station mark is in the floor, a plumb-bob may be hung over it from some mine timber or temporary holder, or a small iron sight rod, say $\frac{5}{16}$ or $\frac{3}{8}$ in. in diameter and 3 or 4 ft. long, a common wire chaining pin, a pencil or a similar

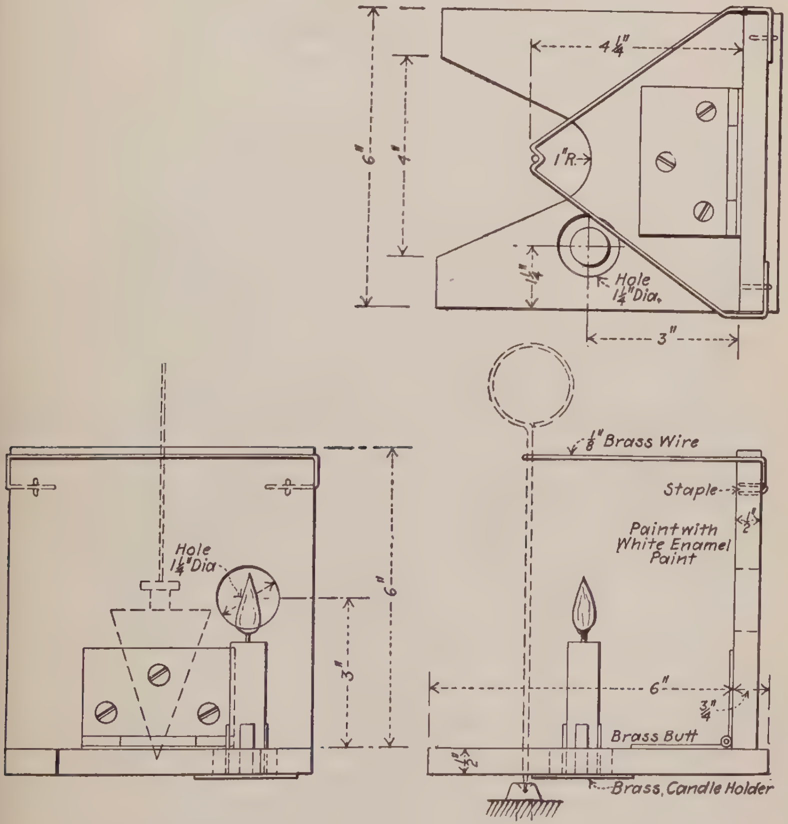

Fig. 14.—Reflector to illuminate the signals.

object may be held on the point, and may be illuminated in the same way as described for the plumb-bob strings.

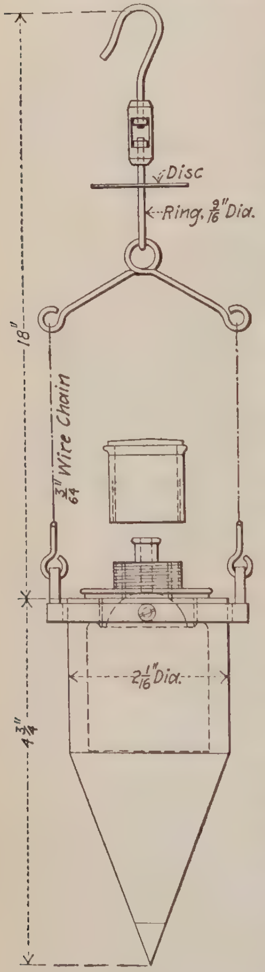

Fig. 15.—Plummet lamp. Made by Heller & Brightly, Philadelphia, Pa.

Sometimes the rear signal and its light is placed in position and then left with a white reflector, consisting of a piece of paper or a clean piece of pine board rigged up behind it. A better reflector, shown in Fig. 14, is made of bright tin or thin wood painted white. The illustration shows the mode of using it. The notch in the base allows it to be placed over a plug in the floor. The top wire will hold a short pin in a vertical position. When not in use it can be carried in the pocket, the wire being folded down against the back and then the bottom up against it. A candle can be set in the hole in the base, or a lamp can be stood on the base.

The use of any fixed signal requires that it have something to stand on at a height where it can be seen from the transit, and the use of an open light requires that it be guarded to prevent it from being extinguished by drafts or by dropping water, and also to prevent it from flickering excessively, which makes the sight uncertain. It usually expedites the instrument work to have a man to hold the light at the proper height and to keep it lighted and the flame steady.

Enclosed lights are not desirable for signals in regular mine work, because they are bulky to carry and the transparent front is apt to be broken or burned. Occasionally under special conditions where it is very wet or very drafty, or the observations will occupy considerable time, or the party is short handed, an enclosed light is useful, and the circumstances will indicate the device to be used. In a gaseous coal mine, where open lights are dangerous, the signal lights must be enclosed safety lamps.

Signals are also used in which the lights are part of the target. There are several types. The hanging or plummet lamps shown in Fig. 15 are used where the stations are in the roof, and they take the place of plumb-bobs. For gaseous coal mines, they are fitted with bonnets like safety lamps. The sight is taken to the wick tube, which is about $\frac{1}{4}$ in. in diameter and can be seen by means of the light from the flame above it, and is easily bisected. On long sights the flame itself is all that can be seen and the sight is taken on this. Tripod lamps, shown in Fig. 16, are used under other conditions; they fit the tripod used for holding the transit and are interchangeable with it. Their special application will be mentioned when describing methods of surveying. A tripod signal is also made which has a transparent

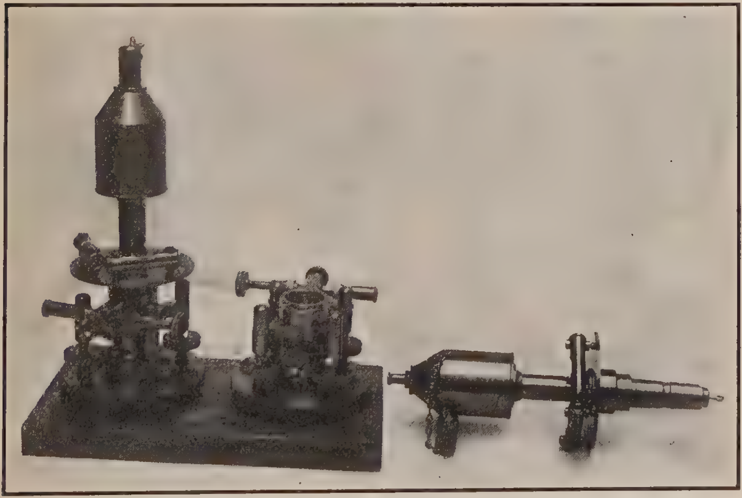

Fig. 16.—Tripod lamps. Made by W. & L. E. Gurley, Troy, N. Y.

target with cross-lines on it, which is illuminated by an enclosed lamp behind it, see Fig. 17. The signal is interchangeable with the transit and is used the same as the open tripod lamps.

Levels.—In leveling in underground passages there is so little head room that a short rod is necessary and the operations can only be carried on where the inclination of the passage is small. Mining rods are made with graduations like either a New York or a Philadelphia rod. The latter, used with a dumpy level, will be suitable for ordinary work. The level will need a reflector for illuminating the cross-hairs, the same as a mining transit. The regular mining rod is 3.3 ft. long when closed and when open reads to 5 ft. Another size, 5 ft. long and opening to 9 ft., is sometimes used for underground work. It is thus intermediate between the regular mining rod and the standard one, 7 ft. long and opening to 13 ft., which is used on surface. The rod or target must be illuminated for underground work. Attempts have been made to use a box-shaped rod with a trans-

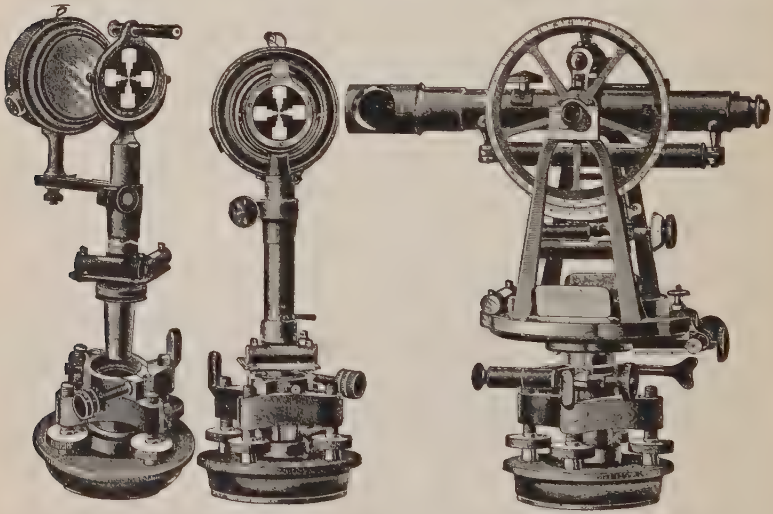

FIG. 17.—Signal lamp. Made by C. L. Berger & Sons, Boston, Mass.

parent front and containing a series of lights, but the apparatus is too fragile. Other attempts have been made to throw light on the surface of the rod from a lamp or candle at the side, but enough light can hardly be furnished to enable the graduations to be read unless the light is set near the point on the rod to be read. As the rodman must thus set the light, he might as well set a target and the attempts to take direct readings might be abandoned.

The best target for leveling underground is an illuminated slit or a horizontal bar silhouetted against a white-ground. The first can be made by cutting a slit across half the face of a leveling target, so that a light can be held behind it. The second can be made by arranging a horizontal wire so that it will project beyond the rod and can be slid up and down. It can be seen by holding an illuminated white surface behind it, as was done with the plumb-bob used for a transit signal. The horizontal bar and the background may be held by the rodman, but a neater apparatus is obtained when they are combined and fastened to a regular target slide and clamp

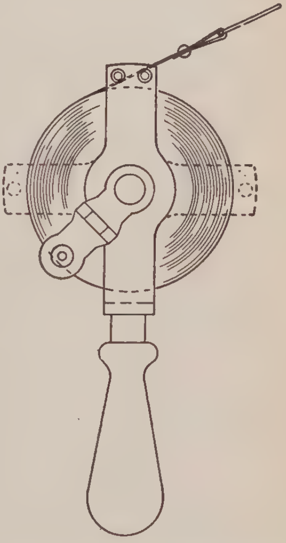

FIG. 18.—Wide tape and reel. Reels with two arms are used for tapes 100 feet and less in length and with four arms for those 150 feet or more in length.

Tapes.—There are two patterns of steel tapes that are useful in mine work. First, wide tapes graduated to hundredths of a foot for their entire length and, second, narrow tapes graduated at 10-ft. intervals.

The wide tapes are usually ½ in. wide, and the graduations and figures are etched on them. They are wound in successive layers on reels. The best form of which is shown in Fig. 18. This form does not collect dirt as readily as the closed cases and is easily cleaned. They are also handy to use and carry. A 200-ft. tape will easily go into a coat pocket.

The narrow tapes are from $\frac{1}{8}$ to $\frac{1}{4}$ in. wide, depending on the make. Those that are $\frac{3}{16}$ in. wide are the most satisfactory. The graduations and figures are stamped on brass sleeves about 1 in. long which are soldered to the tape, or they are stamped on patches of solder fixed to the tape at proper intervals. Either of these devices is satisfactory, provided that there are no projecting corners left to catch on rocks and débris when dragging them along the floor. These tapes are usually 200 or more feet long and are wound on broad reels in irregular layers. These reels are often made with a revolving drum in a fixed frame. Most of them cause trouble by getting bent, by dirt getting in the bearings or if made of wood by the parts swelling with the dampness. The trouble with the moving parts can be overcome by the reel shown in Fig. 19 which has no moving parts. By taking one handle in each hand and giving both a cranking motion the reel revolves about an imaginary center. The reel can be made of sheet iron or of sheet brass, and is easily fixed if broken or bent. The objection to this reel is the tendency for the tape to jump off, but there is no trouble from this source if a slight tension is applied to the tape when either winding or unwinding, and the reel is given the proper cranking

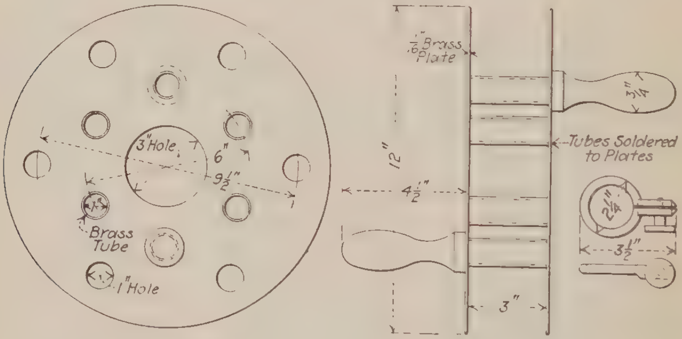

FIG. 19.—Reel and clip for narrow steel tapes.

motion. When it is fully wound the end of the tape may be pushed through one or more of the holes in the side to keep it in place; for transportation the end should also be tied. When the tape is partly unwound the remainder is kept on the reel by running a chip of wood through a pair of the holes. These tapes are used only for long measurements, as the distances between stations, and so are only handled occasionally, and then by two men who are doing nothing else, so that the reel is not seriously inconvenient in practice.

In using the narrow tapes, brass handles are clamped to the tape, one at the zero end and one near the point of measurement. One of these is shown in the corner of the figure. Sometimes the handle at the zero end is omitted and a leather thong is permanently tied into it. By wrapping the thong about the hand it can be used for holding the tape and still the tape may be dragged over the ground without much danger of its catching on rough obstacles.

For an excessively long measurement a wire may be used and marked, then it can be similarly stretched on the ground and the distance between the marks can be measured with a shorter tape.

STATION MARKS

In underground surveying the station points may be in the floor or the roof and in either the rock or the mine timbers.

When the point is in the floor it may be a nail in a tie or other timber, a rivet set in a hole drilled in the rock, or a wooden plug set in a hole and having a nail in it. A nail driven into a timber in the floor is the easiest to put in and it is the poorest kind of a point, as the timbers are liable to be moved or to be knocked out by the shoes of men or mules. It is also the hardest to find again and looks like a nail driven for any other purpose. Such points should only be put in for temporary use. A rivet set in the rock makes the best floor point. Wrought iron boiler rivets, see Fig. 20, are split and provided with a wedge. This may be done by the mine shops. For the $\frac{3}{8}$-inch rivets, a $\frac{1}{2}$-inch hole is drilled into the rock for about the same depth as the length of the rivet. The wedge is started in the slit in the rivet, it is dropped into the hole with the head of the wedge bearing on the bottom of the hole and the rivet is then driven down until the wedge has spread the bottom end of the rivet and filled the hole. If the head is not down to the rock a few hard blows will upset the rivet and let the head jam the mouth of the hole and make it immovable. A point is punched in the top of the rivet with a prick punch. If the rivet is in wrong it cannot be gotten out, but it can be cut off with a cold chisel and so destroyed. A 2-pound hammer should be carried for drilling the holes and setting the rivets. A plug of wood can be set in a hole in the floor

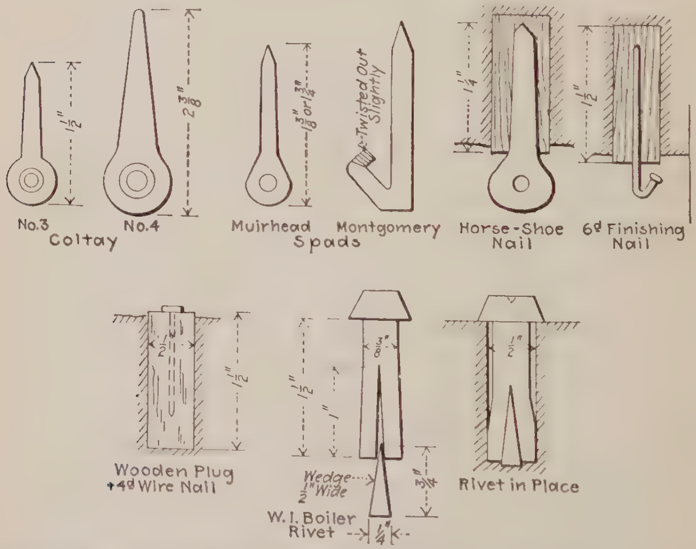

Fig. 20.—Station points. Coltay spads are made by Smith–Courtney Co., Richmond, Va. Muirhead spads are made by John Muirhead & Son, Pittston, Pa. Montgomery spads are sold by Keuffel & Esser Co., New York City.

and a nail driven into it. This makes a fair station point although not as good as the rivet. It is the best to use if the party is not equipped for putting in the boiler rivets, as ordinary miner's hand drills can be used for making the holes and big wooden plugs can be driven into them.

When the point is overhead, it may be a spad driven into some cap, or into a plug set in a hole in the roof. The point set in the plug is more reliable than one in the timbering, as the timbers may move from the pressure on them, especially as they start to decay at their bearing places. In some cases, however, the overhead timbers are heavy and are not subject to displacement unless there are movements of the rock; if that occurs the usefulness of the point is destroyed wherever it may have been placed. The spad is often made from a horseshoe nail, with its head flattened and a hole punched or drilled in it. They are also made out of sheet steel and sold on the market. The latter are made either to resemble the homemade ones, or they are of a special hook shape. Improvised spads can be made from a 6-penny finishing nail bent to form a hook. The spad should be longer than the length of the plug so that it will strike the rock and turn over on the inside end, thus making it harder to pull out.

A block of soft wood for plugs should always be carried in the tool bag. If the holes are all drilled 1½ in. deep, a block of this width cut from the end of a board that is a little thicker than the diameter of the drill hole is very convenient. The grain then runs across the block and a rough plug can be split off with a cold chisel, leaving very little whittling to be done with a knife and no cutting across the grain.

The use of a screw-eye in place of a driven spad, or an expansion-bolt in place of a rivet is not desirable as either can be easily removed by unscrewing and if not actually taken away can be tampered with without showing it.

In coal mines where the roof is often shale, slate or soft sandstone, it is possible to bore the holes in the roof for the station plugs with a flat or twist drill, rotated in an ordinary carpenter's brace, instead of using a drill struck with a hammer. Under these conditions, a small hole say a $\frac{1}{4}$ in. in diameter is sometimes bored, a loop of copper wire is put into the hole, and a plug driven in alongside of it to wedge it in place. The loop should protrude less than an inch, and be pulled vertically before hanging the plumb-bob to it. Another method is to bore a small hole and when setting under it to insert a clip made of flat steel something like a cotter pin from which the bob is hung. When the work at that station is completed the clip is removed. If the station has to be reoccupied a clip is slipped into the hole again to hold the bob.

If the mine water is acid, the station points must all be marked with copper rivets, spads, nails, etc.

In order to facilitate the finding of the station points at a later date, it is well to paint a circle about the point, if it is in the roof, using thick white paint. If the point is in the floor a witness, as a vertical white line, can be painted on the side wall or on a timber if either are near. The number of the station is sometimes painted on the wall or roof, but this is hard to do so that it is legible, and no one but the surveyor is likely to be interested in the number and he can obtain it from his maps and note books, so the addition of the station number hardly pays for the trouble of painting it. Sometimes metal tags, with or without the station numbers, are nailed to the timbers as witness marks. The custom followed on surface surveys of putting three stones 6 to 8 in. in diameter about a stake, can be used to mark points set in the floor of a mine and will be a guide in relocating them, as the stones often remain undisturbed for a surprisingly long time. The stations marked by rivets often can be found by scraping in their vicinity with a stick, after their approximate location has been determined from the description and the notes, the stick will catch on the projecting rivet head if it is hit.

The position of the station points must be carefully chosen, so that the back- and fore-sights are not obstructed by intervening objects, so as to avoid useless set-ups, and so that all necessary details can be collected. The instrumentman should take an active part in locating the stations and in familiarizing himself with the workings before the actual surveying is begun. The position of stations can be marked by a row of candle butts placed so as to give long clear sights, but the surveyor must make sure that the lights which appear to be in good places when on the floor, can be seen when viewed from the instrument, by having them lifted up to the proper heights.

The description of the station points, noted in the field book, should state the character of the point, whether rivet, plug and nail, spad, etc., whether located in roof or floor, how marked with paint, and how it is related to adjacent objects, so that it can be found at a later date if wanted.

A *tool bag* to carry the small stuff is an important part of the outfit. It may be made of duck or light canvas. A convenient size is 12 by 18 in. It should have a flap, a strap and buckle for closing it, and a shoulder strap for carrying it at one's side.

It should contain an equipment for drilling holes and setting the underground stations, which may consist of:

1 2-pound machinist's hammer.
3 ½-inch drills of octagon steel, about 8 in. long.
1 prick punch, ⅝ in. diameter by 4 in. long.
1 cold chisel, ¾ in. diameter by 6 in. long.
1 doz. W. I. boiler rivets, ⅜ by 1½ in., split and with wedges.
2 doz. spads.
2 doz. 4-penny wire nails.
2 blocks of soft wood for plugs.

The bag should also contain extra lamp wicks, extra plumb-bob cords, rags or cotton waste for wiping tapes, etc., and a cord about ⅛ in. in diameter and 100 ft. long wound on a stick. This last is used as a hand line in passing a tape or other small things from one to another, or for getting the details in remote corners.

The bag is used while moving, to carry the small tapes, the detachable tape handles, the extra plumb-bobs, etc., and while at work, any piece of apparatus not in use, such as tripod caps, carrying straps, etc., are kept in it.

The paint pot and oil or candle supply for the lights are kept with the tool bag, and are cared for and moved ahead by the helper. If the signal lamps burn kerosene, a small supply of it can be carried in a can with a screw top, which can be slipped into the tool bag.

If surface stations are likely to be set, the kit should include: a few oak stakes, 1½ in. square by 12 in. long, pointed at one end; two dozen 10-penny wire nails with rags tied to them for temporary marks or for laying out work; and a dozen 60-penny nails for use as station points in frozen or very hard ground.

PERSONAL EQUIPMENT

Clothes.—In general, the clothes worn by the miners in any district will answer the needs of the surveyor and will suit the local conditions. Usually, the men wear an overall suit over coarse clothes of the ordinary type. These overall suits are usually heavier than those worn by mechanics and consist of pants and a coat. They resemble a hunting suit in many ways except that they are cheaper. In some localities these miners' coats have a warm lining of blanket-like material.

As the temperature of most mines is about 50° at all seasons of the year, the surveyor may need to wear a woolen undershirt when going underground even with a lined coat. Where the winter weather is cold, the uniform temperature of the mines seems warm, and less clothing is needed underground than on surface. As the mine clothes are too dirty to wear under an overcoat, and it is often inconvenient to change the clothes at the mine, an ordinary heavy coat or a sweater can be worn under the mine coat, if it is large enough, in going to and from the mine, then on reaching the mine the extra under coat can be left on the surface. On coming out of the mine, if the work coat is wet from dripping water, the spare coat goes inside and the wet surface is still outside and does no harm. In extreme cases, it may be necessary to wear waterproof clothing in the mine.

Hats used in mines usually resemble "southwesters" and keep both water and dirt out of the neck.

For foot wear, lace shoes that are 10 to 12 in. high with bellows tongues are the best. These are not so clumsy as boots as they only reach part way up to the knees. The trousers should be neatly tucked into the tops of them when lacing them up. Then as the overalls are allowed to hang over the shoes very little dirt can work into them. The heels and soles of the shoes should have hob nails driven into them. The hob nails should be iron and not steel. Steel nails wear smooth, while iron ones wear rough and never lose their holding power on rock surfaces. There are many patterns of hob nails but the Hungarian nails with small half round heads are preferred, and the local cobbler at the mine can usually supply them. The hob nails should not be too thickly set in the shoes. There should be a row around the heel and around the sole close to their edges, a few in the center of the heel, and four to six rows across the sole. The nails should be about $\frac{1}{2}$ in. apart in the rows. No nails are needed in the hollow of the shoe. Care must be taken that none of the cross rows of nails on the sole come exactly under the ball of the foot, or the wearer will find that he is walking constantly on a ridge that will make him foot sore. For very wet mines, it may be necessary to wear rubber boots, as no leather shoes are really waterproof when it is necessary to stand in water for a considerable length of time.

Lights.—In mine work every member of the party must have a light with which to see to travel, and the lights used by the miners in the district will generally be found to be satisfactory for this purpose. Each member should carry matches and material to replenish his light when it becomes exhausted, as his safety depends on his having an individual light. The transit man will find it convenient to wear a hat lamp which will give general light about him and leave both hands free to manipulate the instrument or take notes. He should also have a second light hanging near, often from the tripod leg, which he may pick up to light the verniers in reading them, for illuminating the cross-wires, or for signaling to his assistants. The miners' oil used by the workmen is usually a cheap product, that burns with considerable smoke in the open lamps, hence it is desirable for the survey party to carry a better oil, as lard oil, for their lamps, which makes a less offensive smoke. Any lamp that is used near the magnetic needle should be of brass for exact work, but where the readings are taken only for check purposes a tin lamp may be used provided it is held so far above the instrument as not to effect the needle. A few trials will show to what extent this use of a tin lamp is safe.

Owing to the dirty condition of the hands, when burning oil, some surveyors use candles for their instrument lights, although they give less light than lamps. The droppings from candles soon harden and can be scraped off the instruments, hands, and note books, and they do not collect dirt as badly as does oil. Candles are held in miners' candle sticks, made of wrought metal, or in holders made of wire.

An acetylene lamp is a valuable addition to the transitman's outfit, as it is useful in exploring the workings in order to lay out the method of procedure for the survey and it can be hung on the wall to illuminate the vicinity of the transit while the station work is being done and so facilitate the recording of the notes. They are too heavy and clumsy to wear on the hat or to use for vernier reading.

Electric lamps have been advocated for reading the verniers. In some cases the current is supplied by storage batteries in a box which can be carried from the shoulder by a strap or with the other parts of the kit and the lamp is attached to the end of a flexible cord. This lamp is convenient in form to use at the instrument, but the 2-pound battery is objectionable. "Flash lamps" with the lamp and battery in one case might be used to advantage for reading and signaling, but they must be used economically, as the life of the battery is short if used constantly. The cases are rather clumsy to use near the verniers but this is overcome by a lamp made especially for vernier reading.[1] Electric lamps cannot be used for reading the needle.

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[1] Made by Keuffel & Esser Co., New York City.

The greatest objection to special reading lamps is that they increase the equipment that has to be carried and cared for.

SIZE OF PARTY

An instrument man, one assistant and a handy man make a convenient party. The assistant should be able to help with the instrumental work, the calculations and the mapping when occasion requires. The handy man may be a miner, but more likely he will be a laborer who is handy with tools, and who is familiar with the mine.

The assistant sees that the fore-sights are properly set, helps with the taping and other important parts of the work, leaving the instrument man free to attend to the instrument and the notes. A hustling, thoughtful assistant can do much to expedite the work by having everything ready when wanted. The helper can be left to care for the backsights already set and protect their lights, can set station points after they have been located by the surveyor, can care for the tool bag and minor instruments, and attend to many small details.

In the coal mines larger parties are often used but there the transit work, the taping and leveling are distributed among different squads, something as in railroad surveying. This special organization is described in Chapter VII.

CHAPTER III

UNDERGROUND TRAVERSING

SETTING UP THE TRANSIT

It is considerably more difficult to set up a transit in underground workings than on surface and the tripod with three extension legs is often indispensable. The rule that two tripod legs are to be placed on the down hill side and one on the up hill side must be more faithfully observed than on surface, in order to get a firm set-up, as the floor is solid rock and the legs cannot be pressed down into it. A considerable amount of stability is given to a set-up by leaning a large flat rock, say 15 by 8 by 4 in., against each leg after setting it. This takes the place of pushing the points into the ground. Standing room must be obtained about the instrument, so that the operator can make the necessary changes in his position without danger to himself or without jarring the instrument. The position of the transit must be such that the signals on both sides of it can be seen readily. This has to be looked after very closely as there is often a stray timber, a low place in the roof, or even a wire close to the telescope, that will interfere with the sight, and that has not been noticed when the points were set.

There are several advantageous features in underground surveying; there is seldom any wind and the plumb-bobs hang dead, the temperature is uniform and there is no unequal expansion of the instrument or of the leveling tubes. The conditions are strange to a surface surveyor, but they are very uniform and good work can be done.

The most difficult set-up to make is one *under* a station point. Some surveyors plumb down from the point in the roof to a disc of lead laid on the floor. This disc has a point marked on it with a tack, a pit or a cross-mark, and it is placed exactly under the station-bob, which is then removed, and the transit is set up over the disc. The disc is liable to be moved without any means of detecting the movement and, for this reason, the method is not as reliable as setting the transit under the station-bob.

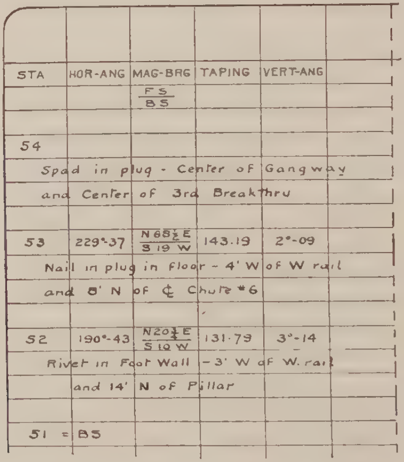
In setting under a station in the roof, the bob is hung from the spad, and the tripod is set approximately right and good places found for the legs, so that the head is fairly level. Then the transit is attached, it is roughly leveled with the screws and the legs raised or lowered until it is nearly under the bob. There is usually a screw head or some mark on the top of the telescope at the intersection of the horizontal axis and the center line of the telescope, which is over the center of the instrument when the latter is level and the telescope is horizontal, and this mark is brought exactly under the bob for the final setting by a succession of alternate shiftings and levelings. In setting under a point the shifting head is invaluable and the adjustable plumb-bob is very convenient.

The transit should always be leveled with the long bubble before taking vertical angles, and it is an advantage to so level it at the beginning of any set-up, then the transit is in the best condition to measure the horizontal, as well as the vertical angles with accuracy, and when the transit man is in the habit of doing it, it can be done very quickly.

METHODS OF TRAVERSING

Plummet Method.—The plummet method of surveying is analogous to the method of surveying on the surface with rods, where the vertical angles are read solely to reduce the tapings to the horizontal. It is a convenience to have all the station points in the roof or in the overhead timbers, then the signals can be either the plain plumb-bob or the plummet lamps, and can be hung directly from the spads. If it is necessary to place some of the points in the floor, then the sights may be taken to any slim object placed vertically on the point.

The transit work consists of reading the horizontal angle by the method adopted for the survey, the magnetic bearings both backward and forward, and the vertical angle if the taping cannot be done horizontally. The vertical angle should be read to a knot in the plummet string or to some similarly defined point, and the tapings should be made from the axis of the instrument to this same point. With points in the floor, the vertical angle and taping can often be made directly to the top of the point. In level gangways, with only grade enough for drainage, that is about one-per cent., the tapings can be measured on or parallel to the floor, and between plumb-bobs hung from the stations, without considering the vertical angles. In this class of workings, the taping is sometimes done with a 100-foot tape, measuring along the floor, marking the end of each 100 ft., and lining-in the forward or marking end of the tape with the transit. More accurate work would result from using a long tape and measuring in one stretch.



STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	
		FS BS			
54					
Spad in plug - Center of Gangway					
and Center of 3rd Breakthru					
53	229°-37	N 68½ E S 19 W	143.19	2°-09	
Nail in plug in floor - 4' W of W rail					
and 8' N of ℄ Chute #6					
52	190°-43	N 20¼ E S 19 W	131.79	3°-14	
Rivet in Foot Wall - 3' W of W. rail					
	and 14' N of Pillar				
51 =	BS				

FIG. 21.—Form of field notes for a survey by the plummet method. Left hand page. Elevations not carried.

The form for keeping the notes of a survey run by this method is given in Fig. 21. The horizontal angles in this example have been read directly and only once, but any desired method of angle reading might be used. The notes are recorded from the bottom of the page and proceed upward, and the descriptions of the stations are given, as recommended in Chapter I.

The elevations with the above method of traversing are obtained by running a line of levels with standard leveling instruments and hence the method is applicable only to flat workings.

An example of the use of the plummet method to the survey of flat workings is given in Fig. 22. Here a vein having a dip of 10° is reached by a tunnel which is practically level and the drifts on the vein closely follow the contour of the floor and have only a slightly rising grade as they leave the main tunnel. The survey was started from an initial monument at the mouth of the tunnel and stations were set on the center line of the tunnel as it progressed to serve as guides in driving it. When the survey of December 1905, was made, the work had reached the junction with the vein and the drifts had been started. The next survey was made in June 1906, and was carried along the north drift to beyond Sta. 7 and included the survey of the first stope, and along the south drift to beyond Sta. 8. In December 1906, the south drift had not been advanced since the June survey, but the north drift had been advanced and the survey was run to beyond Sta. 9, and included the survey of Stopes 1 and 2. In June 1907, on the south side, the survey was extended in the drift to Sta. 10, and on the north side, the first stope had become so large that Sta. 11 was located in it and the survey of the stope was brought up to date from the new station, the survey of the drift was prolonged to Sta. 13, and additional surveys were made in Stopes 2 and 3. On these various surveys, the tapings were all made horizontally except that from Sta. 6 to Sta. 11, which was corrected by a vertical angle. The levels were obtained at a later time by leveling methods, using a short rod. The details were obtained by offsets from the survey lines and by radiating sights from the transit

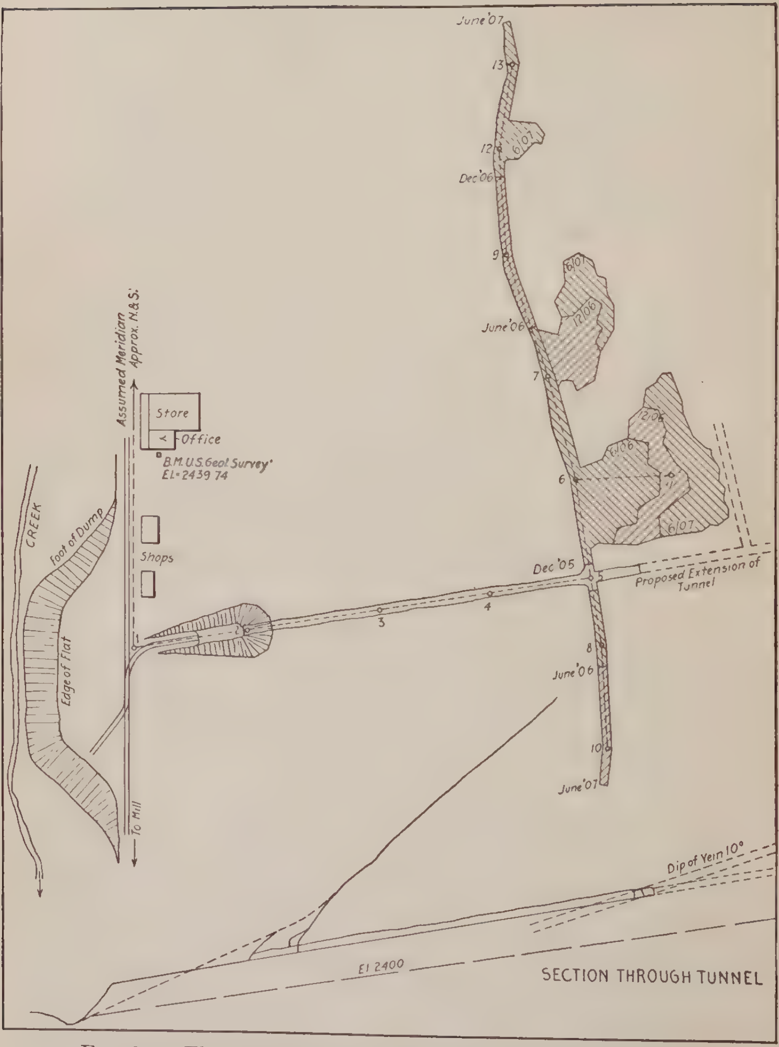


FIG. 22.—Flat workings surveyed by the plummet method.

stations, as is discussed in Chapter IV. The successive stages of the mining operations are shown by the dates and the variations in the hatching on the map.

When the workings have a steep inclination, the levels cannot be obtained with a leveling instrument, as the horizontal lines of sight will strike the roof in too short a distance to make the work practical. Under these conditions, the elevations have to be determined by means of the taped distances and the vertical angles. On the surface, the tapings and vertical angles are sometimes taken on a line parallel to the station points, by measuring the

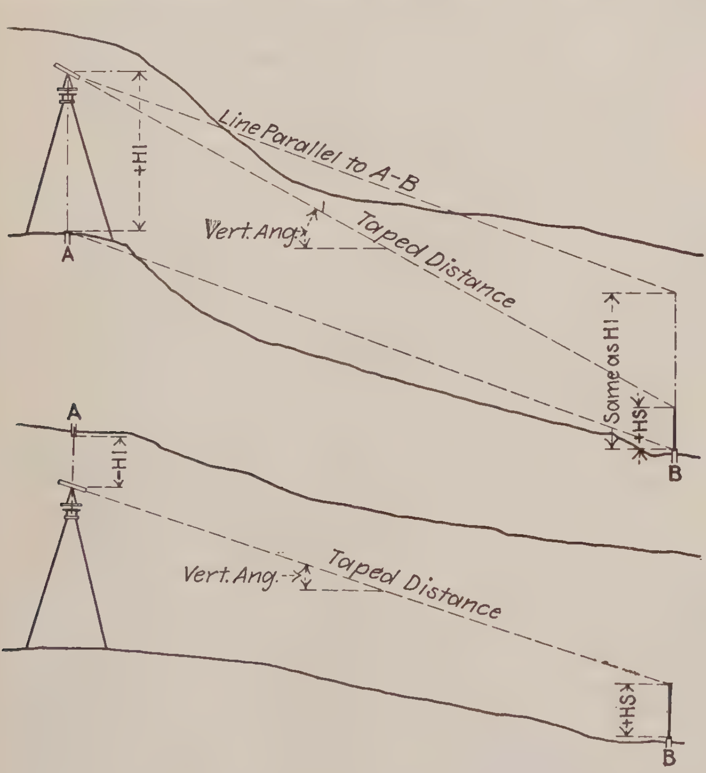


FIG. 23.—Impossibility of taping parallel to stations.

height of the transit and observing the vertical angle to a target set at the same height above the next station point. Then the inclined distance multiplied by the sine of the vertical angle gives the difference in elevation between the two stations. Sometimes this method is practical in underground work, but generally it is impossible to sight from one station to another on a line parallel to the station points, as there is apt to be an interference from an overhead obstruction, or some of the survey points may be in the floor and some in the roof, see Fig. 23.

Whatever the arrangement of the stations, the necessary data for the solution is given by taking the height of the transit and the height of the signal at every set-up and entering these in the note book in two columns headed height of instrument (*H.I.*) and height of signal (*H.S.*). These heights must also be preceded by a sign to indicate the direction of the measurement, using plus for all heights that are measured up from floor points and minus for the distances that are measured down, that is for the negative heights, from roof points.

The elevation of a second station, as Sta. *B*, when observations are taken from the known station, *A*, can be found by the formula:
Elev. B = elev. $A + (\pm H.I. \text{ at } A) + (\pm \text{vert. dist.}) - (\pm H.S. \text{ at } B)$.

In the second member, the first term should be positive and quite large, as it will be if the datum for the elevations is taken at some distance below the mine workings; the sign inside the parenthesis of the second and fourth terms will be plus when the station point of the instrument or signal is in the floor and minus when it is in the roof; and the sign inside the parenthesis of the third term will be plus when the vertical angle is upward and minus when it is downward. The eight cases that may arise with the appropriate formula for each are shown in Fig. 24.

The form of notes for this method is given in Fig. 25. Sta. 38 shows the notes at a station located like Case 3*a* and Sta. 37 is similar to Case 4*b*. These are typical of the whole series.

If the taping and vertical angle are repeated on the backsight as a check, they may be entered under their respective headings but on a line prefixed with the note "*B.S.* check." This leaves

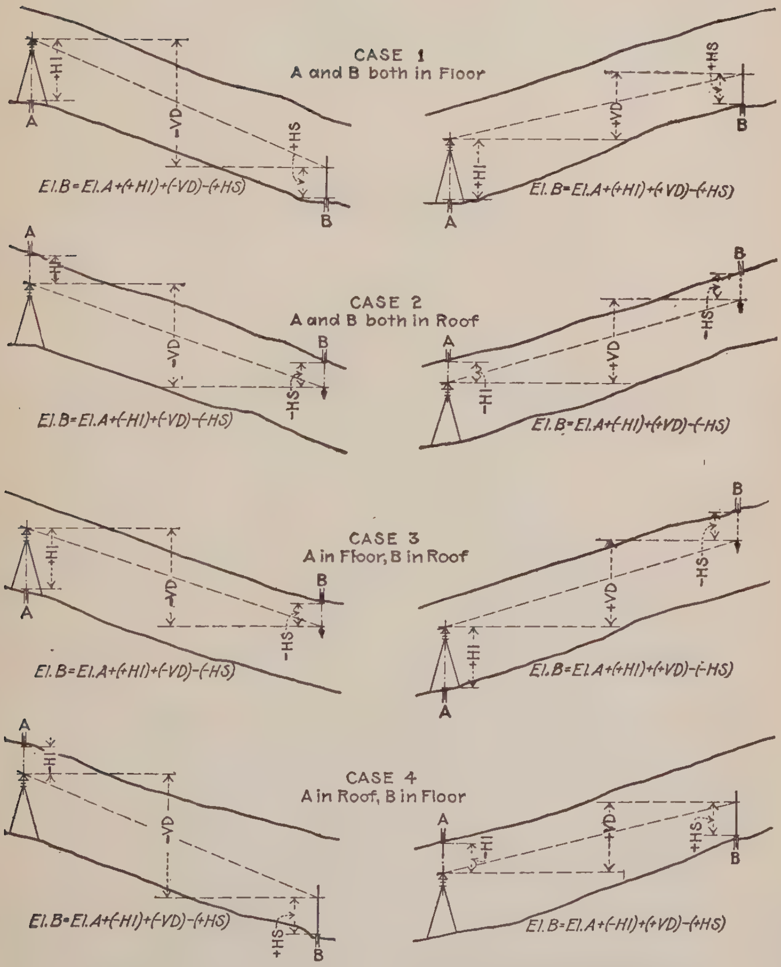
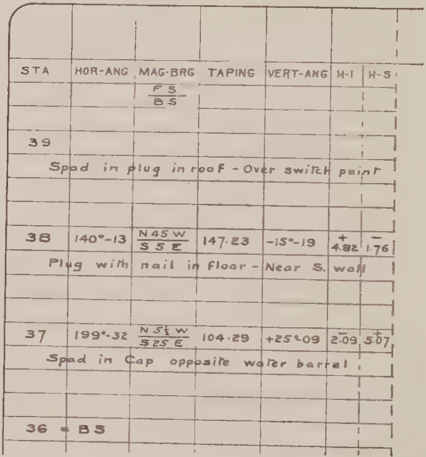

CASE 1
A and B both in Floor
A
B
+HI
-VD
+HS
El.B=El.A+(+HI)+(-VD)-(+HS)
+HI
+VD
+HS
El.B=El.A+(+HI)+(+VD)-(+HS)
CASE 2
A and B both in Roof
-HI
-VD
-HS
El.B=El.A+(-HI)+(-VD)-(-HS)
-HI
+VD
-HS
El.B=El.A+(-HI)+(+VD)-(-HS)
CASE 3
A in Floor, B in Roof
+HI
-VD
-HS
El.B=El.A+(+HI)+(-VD)-(-HS)
+HI
+VD
-HS
El.B=El.A+(+HI)+(+VD)-(-HS)
CASE 4
A in Roof, B in Floor
-HI
-VD
+HS
El.B=El.A+(-HI)+(-VD)-(+HS)
-HI
+VD
+HS
El.B=El.A+(-HI)+(+VD)-(+HS)

FIG. 24.—Determination of elevations by a plummet survey.

the entry opposite the station to refer only to the foresight observations.

Three Tripod Method.—This method is designed to facilitate the obtaining of elevations in connection with the traverse in steeply inclined or uneven mine workings, where a leveling instrument could not be used.



STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	H-I	H-S
		F S B S				
39						
Spad in plug in roof - Over switch point						
38	140°-13	N 45 W S 5 E	147.23	-15°-19	+ 4.82	− 1.76
Plug with nail in floor - Near S. wall						
37	199°-32	N 5½ W S 25 E	104.29	+25°-09	− 2.09	+ 5.07
Spad in Cap opposite water barrel						
36 – BS						

FIG. 25.—Form of notes for a survey by the plummet method. Left hand page. Elevations to be carried.

Three tripods are provided, all alike and all of the extension style used for the transit. One is set up at the transit station, and one at the back and one at the forward station. A tripod lamp, like Fig. 16, is placed on both the foresight and the backsight tripods, and the transit on the center one.

The horizontal angle is read from the transit by sighting on the centers of the wick tubes of the signal lamps, which can be seen just under the flame. The angles may be measured by any desired method, but it is preferable to do it by repetition, using a set of at least four observations, see page 14. The vertical angle is read to the top of the wick tube and should be observed with the telescope in the normal and checked with it in the reversed position. The distance, from the horizontal axis of the instrument to the top of the wick tube of the signal is taped on the line on which the vertical angle was measured. The height of the instrument from the point to its horizontal axis is measured and noted. It is called plus if it is measured upward from a point in the floor, and minus if measured downward from a point in the roof. This finishes the observations at any one point.

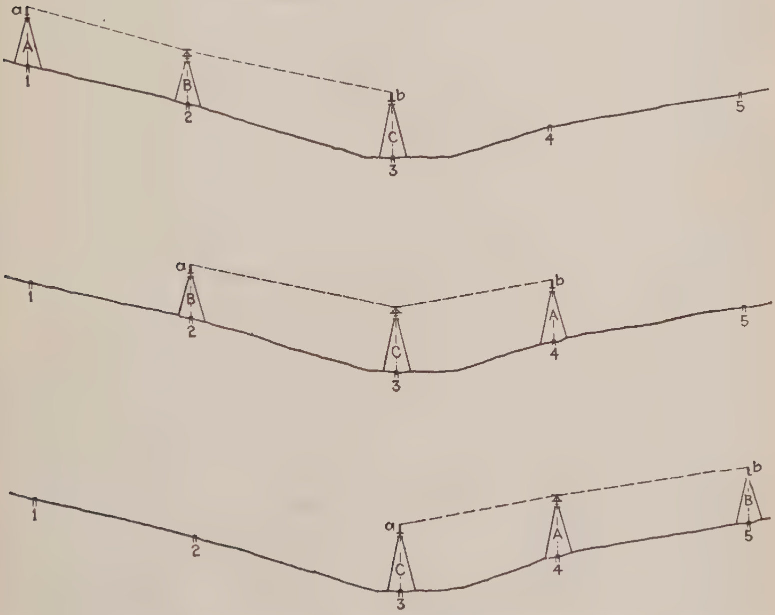


Fig. 26.—Three tripod method. Showing the successive use of the tripods for lamps and transit.

The backsight lamp and tripod are pulled up from Sta. 1, and are brought forward; the transit is taken off the tripod at Sta. 2, and the lamp from the rear station is put in its place; the transit is taken to Sta. 3, which was the former foresight, and put on that tripod in place of the lamp; and the lamp from Sta. 3 with the tripod from Sta. 1 are set up as the new foresight at Sta. 4. This succession of set-ups and uses of the lamps and transit is shown graphically in Fig. 26, where each tripod and lamp is given a letter, and its successive positions can be followed.

By this method there are three tripods in use, but there is only one new one set up for each set-up of the transit, after the survey has been started, and that is the foresight tripod, which is used in different capacities for three consecutive angle readings before it is moved.

The tops of the wick tubes of the lamps are the same height above the tripods as the horizontal axis of the transit, so after their interchange the transit and the signals are at exactly the same heights as they were on the previous sight. This arrangement allows the elevations to be determined from the traverse by easy calculations and the field notes are simple. Thus, if the elevation of the instrument station is given, the algebraic addition of the height of the instrument gives the elevation of the instrument; then the elevation of the signal at the forward station is found by adding algebraically the vertical distance given by the vertical angle and the taped distance; this elevation of the signal is also the elevation of the instrument when the transit is set on that station, and the algebraic additions of the following vertical distances give the elevations of succeeding signals. The elevations are thus carried along on the line of sight irrespective of the height of the instrument from the station point, and also independently of whether the instrument is above or below the station point.

Elevations could be carried indefinitely by this method without paying any attention to the height of any of the instruments except the first, but as soon as the tripods were pulled up the positions that the instruments occupied would be lost and the record of their elevations would be of no value, hence the height of the instrument at each station is measured and this subtracted algebraically from the calculated elevation of the instrument, gives the elevation of that station point. This is shown graphically in Fig. 27, and the detail calculation is given below the figure.

In a continuous traverse, the height of the instrument is noted when the tripod is occupied by the transit, except that on ending a traverse, either temporarily or permanently, the height of the last forward signal must be noted or the elevation of that station point cannot be found.

The taping for the three tripod method of surveying must be done with a tape that is long enough to reach from the transit to the signal in order to be of use in obtaining the elevations by the vertical angles. On important work and especially on long distances, the tapings should be corrected for the sag, see page 24.

The form of notes for the three tripod method of surveying is shown by the samples at the end of Chapter IV. The purpose of the various entries is discussed under the Sample Survey on page 59.

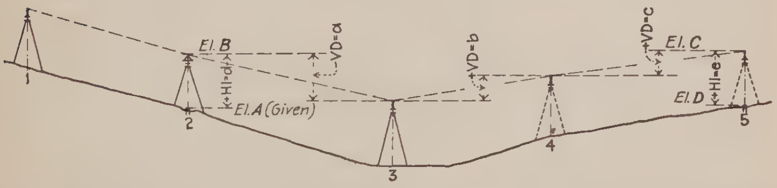


FIG. 27.—Carrying elevations by the three tripod method. Given: Elevation of station $2 = A$; height of instrument at $2 = d$; vertical distances, a, b, and c by calculation; and height of instrument at $5 = e$.

The elevation of the instrument at the first station = the elevation of the station point *plus* the height of instrument noting its sign, thus, elev. of inst. at $2 = A + d = B$.

The elevation of the instrument at any station = the last known elevation of instrument *plus* the algebraic sum of all the intermediate vertical distances thus, elev. of inst. at $5 = B + (-a) + b + c = C$.

The elevation of any station point = the elevation of the instrument at that point *minus* the corresponding height of instrument noting its sign, thus, elev. of sta. $5 = C - (+e) = D$.

In order to provide an additional check on the distances and elevations in important work, the vertical angles can be read on the backsight and the distance be re-taped. They should both agree with the foresight observations on the same course if the tripods have not been moved, as the instrument and signals are at the same point in both cases, but the inclination will be reversed. If this backsight check is made on the first course of the traverse or after a resetting of the tripods, the height of both the transit and the back signal must be measured, as they are probably different from the original setting and the vertical angle and distance will not agree with the previous observation, but the resulting horizontal and vertical distances should agree with that previously obtained.

A temporary survey can be run by the three tripod method without using any station points if desired, by simply setting up the tripods and taking all measurements from them. This may be used to run the survey to some remote corner, to get the details for plotting. It is safer, however, even with a temporary line, to set over some simple point, as a nail driven in the dirt or into a piece of board held in place by rocks, so that if a tripod is disturbed while being used, the movement can be detected and the tripod be replaced. These stations would be entered in the note book as "temporary," see Sta. 14, 15 and 27, in the "Field Notes," at end of chapter IV. No description is given, and no height of instrument is measured for temporary stations. These stations would be plotted on the map in pencil, would be used merely for plotting the details and would not appear on the finished map.

.The use of firm tripods to support the signals and to give points for taping allows the traverse to be made with the highest degree of accuracy attainable with a transit survey, and the three tripod method with the tripods used alternately as signal bearers and as transit supports, gives the maximum speed, as it saves the setting of tripods that are only useful to hold signals. The advantages of the three tripod apparatus and method of surveying are so great, that many mine surveyors use them on their surface work. On surface, in good light, a finer sight for horizontal angles can be obtained by sighting on the bob cord, under the tripod than by sighting on the wick tube, if there is no wind. The vertical angles, however, must be taken to the top of the wick tube so that the height of the sight point will be the same as that of the instrument, when it is moved ahead. This necessitates taking the lamps into the field, unless a special signal is made to fit into the tops of the tripods and of the same height as the lamps. In several cases on surface, where the sights were very long, and the refraction interferred with the sights in the day time, the lamps have been found to give clear sights when used on calm nights.

If the elevations are determined by a line of levels taken with a Y or dumpy level, which can readily be done on surface, the observations for elevation can be omitted from the traverse and the vertical angles will only be needed to reduce the tapings to the horizontal. The lamps or other signals can then be omitted from the tripods, the horizontal observations can be made on the plumb-bob cord and the tapings and vertical angles can be measured to a knot in the cord. This combination of the three tripod method for the traverse and the level for elevations will give the greatest accuracy for surface work.

Sample Survey.—An example showing a survey by the three tripod method of an hypothetical mine on an inclined vein will bring out the details of the method under the various conditions that occur in such mines and will give the data for the subsequent operations leading to the completed map.

The Blank-Blank Mine had been opened for some time before this survey was made. A sketch showing the plan of the mine is given in Fig. 28. In July 1906, the large stope on the First Level North caved in from the surface, completely closing the north end of the drift. The outcrop of the vein was supposed to be near the line *A-B-C* at which points the vein was exposed, but the cave showed that it lay under a deep covering of earth, for a considerable distance between *B* and *C*, and that the thickness of the rock over the workings at this point was less than was supposed. To prevent further accidents, the outcrop was uncovered at several points marked *T*, and these and the underground workings were surveyed and plotted on a map in August 1906.

A preliminary survey determined the center line of the slope which had been driven straight and this line was prolonged to an intersection with the meridian, which had been established three years previously by a U. S. Mineral Surveyor, this intersection gave the point, called Sta. 1, which was used as the origin for both the survey and the subsequent calculations.

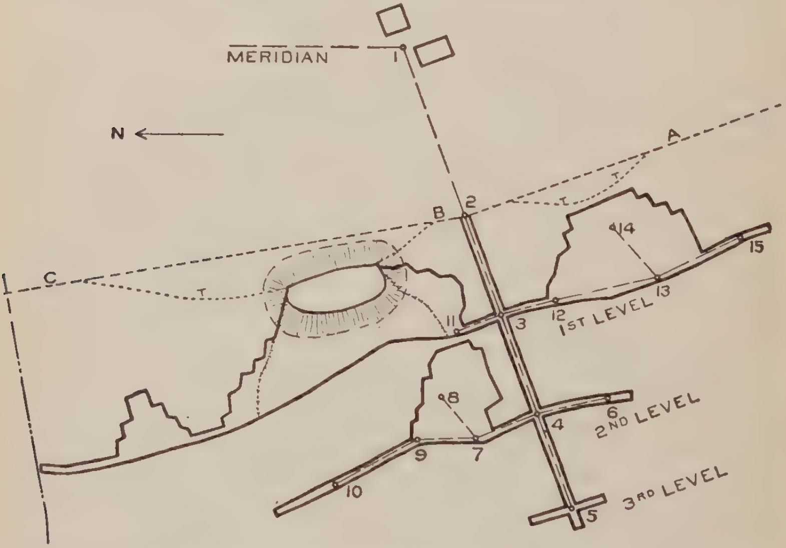


FIG. 28.—Sketch 1 of the Blank–Blank mine at the time of the first survey, August 1906.

The survey of the mine was run by the three tripod method. It was started at Sta. 1, with a backsight taken along the meridian, and run down the main slope, Sta. 2 to 5 being set and successively occupied. They were all in a straight line. The forward station in each case was set as a mean of several positions determined by sighting on the rear station and plunging the telescope, half of the observations being taken using the telescope normal on the backsight and half with it reversed on the backsight. After setting Sta. 5, there was a tripod on each of Sta. 3, 4, and 5. The transit was moved to Sta. 5, a lamp placed on Sta. 4, and radiating sights taken into both the north and south drifts on the Third Level from which the details were obtained. The transit was then moved back to Sta. 4 and the tripod moved from Sta. 5 and set at Sta. 6 as a foresight, the lamp still remaining on the tripod at Sta. 3 was the backsight. When Sta. 6 had been located, the details at the head of the drift were determined from it. Next, with the transit at Sta. 4, the tripod from Sta. 6 was set at Sta. 7 with the foresight lamp. When it had been located, the rear tripod and lamp on Sta. 3 was pulled up. The tripods at Sta. 4 and 7 being in place, Sta. 8 was located and occupied by the transit and the details of the stope were taken by radiating sights, then the transit was reset on the tripod at Sta. 7 and the tripod on Sta. 8 was moved to Sta. 9, which was then located. From Sta. 9, Sta. 10 was located and the details of the drift were determined. Then returning to the main slope, the transit and tripod were reset at Sta. 3, a backsight was taken on a pin held on Sta. 2, it being in the daylight, and Sta. 11 and 12 were located. From Sta. 12 the traverse was continued and Sta. 13, 14, and 15 were set. The notes of these surveys are given on pages 1 to 5 of the "Field Notes" at the end of Chapter IV.

By carefully planning the order of the work, the needless setting of tripods was avoided; thus, the tripods on Sta. 3 and 4 were not moved during the occupation of Sta. 5 and 6; the tripod on Sta. 4 and 7 remained unmoved during the location of both Sta. 8 and 9; the set-up at Sta. 3 was used for setting both Sta. 11 and 12; and Sta. 14 and 15 were set without moving the tripods at Sta. 12 and 13.

Referring to the "Field Notes" there are several items worthy of special mention. First, the instrument work at Sta. 2, 3, and 4 on page 1 did not follow the usual process of reading the angles by repetition, and to make the field work clear, a special note was introduced and attention was called to it by the star after the station numbers. The magnetic bearings were also omitted. Second, the monogram of *C* and *L* in the note means center line. Third, Sta. 5, being the last point down the slope, had no traverse work done from it, so there are no angle entries but the height of its set-up is noted, in order to determine the elevation of its station point. Fourth, the notes in the rectangles, appearing on every page and reading "Posted on Sheet—," were added in the office with a rubber stamp or with ink and show that the notes have been transferred to the specified Record Sheet, where the calculations for these stations can be found, see Chapter V. Fifth, on page 2, Sta. 4 recurs and the reference, made to page 1, connects it to the previous work; no new description is necessary in this case, unless the surroundings have been materially changed since it was used before. The height of the instrument being the same as on page 1 of the notes, indicates that it is probably the same set-up. Sixth, Sta. 14 and 15 were set from Sta. 13, see page 5, merely to get the details in those parts, the conditions being such that it was not desirable or feasible to set permanent points, hence those stations were noted as "temporary" and no description was given. The horizontal angle to them was only read once as no future work depended on them, and as there was no station point, there was no *H.I.* to be measured. In these cases, waved lines are often drawn to show that there are purposely no entries, and that they have not been omitted by accident.

In December 1906, the workings had advanced to the condition shown in Fig. 29, the parts excavated since the August survey being hatched, and a system of regular semi-annual surveys was begun. On the Second Level South, Sta. 16 and 17 were located and the details determined. On the north, Sta. 8 and 9 were reoccupied and additional details of the stopes were taken. A winze had been pushed up from the top of the stope to locate the drift on the First Level, which had been filled by the cave-in of July, and to determine the thickness of the solid ore above the stope and so prevent a repetition of the caving. The drift had been extended to the north, and Sta. 18 and 19 were located and the details determined. A stope having been started opposite Sta. 10 and another opposite Sta. 19, radiating sights were taken into each of them, when occupying those stations with the transit. On the Third Level, there had been extensions both north and south, so Sta. 20 to 23 were located and the details of the new work were determined. The main slope had been extended a short distance. The notes of these December surveys, given on pages 6 to 8 of the "Field Notes.

By April 1907, the workings on the Second Level North had been carried up and had broken through into the old workings on the First Level, at a point above Sta. 10 but under the débris, and at a point above Sta. 19, beyond the caved material, as shown by Fig. 30. A survey of the Second Level was made immediately as a basis for plans to get out the ore at the north end of the First Level by way of the Second Level. Sta. 8, 9, and 10 were occupied and the details of the stopes were brought

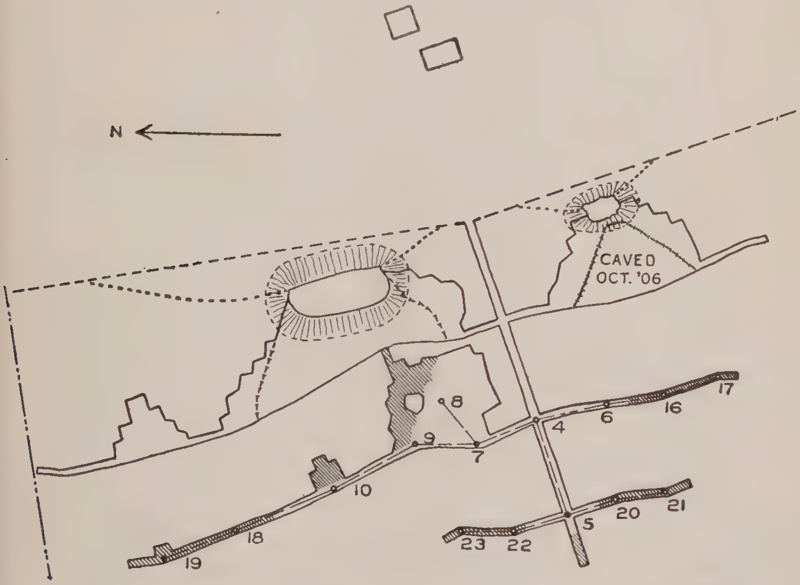


FIG. 29.—Sketch 2 of the Blank-Blank mine at the time of the December 1906 survey.

up to date, but no traverse work was done from them. From Sta. 19, Sta. 24 at the north end of the Second Level was set and the details determined here as this drift was approaching the end of the property. From Sta. 19, the traverse was run up the winze to the First Level and Sta. 25 to 28 were successively located and occupied and the details were determined.

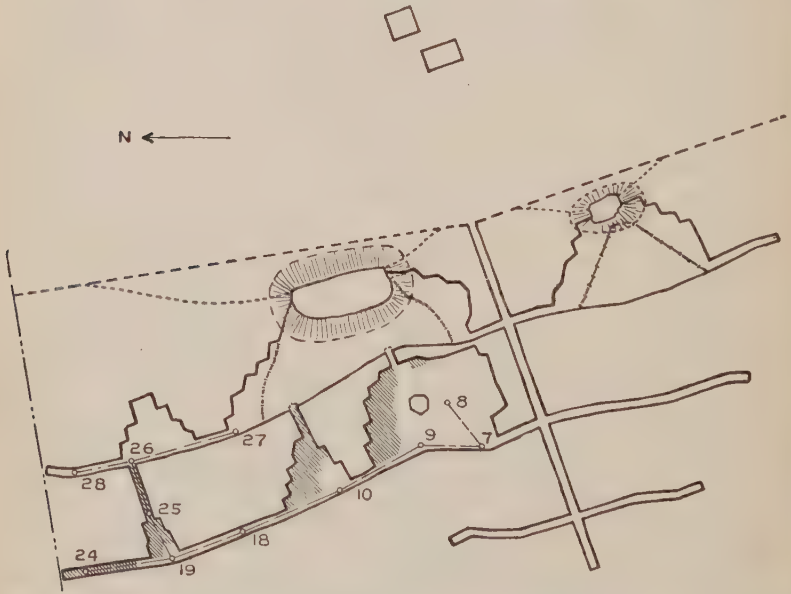


Fig. 30.—Sketch 3 of the Blank–Blank mine at the time of the April 1907 survey.

The other parts of the mine were not surveyed at this time, that work being left until the semi-annual survey in June. The notes of this April survey are given on pages 9 to 11 of the "Field Notes."

The methods of collecting the details which appear on the right-hand page of the "Field Notes" are given in Chapter IV and the calculation and plotting of these same notes are worked out in Chapters V and VI.

The survey of this mine and the reduction of the notes to a plot are typical of the operations of running a survey by the three-tripod method and a study of these notes, calculations and plot will illustrate the processes used without a tedious discussion of the individual steps.

CHAPTER IV

SURVEYING FOR DETAILS

The traverse that has been run through the mine is the base for determining the details and when plotted forms the skeleton on which the map is built. The traverse alone gives little idea of the workings. The details are required in order to record and describe the excavation that has been made. The notes for the details are usually recorded on the right-hand page of the note book opposite the stations which form the base traverse, so all all the data for the given area are together. The traverse notes on the left-hand page are recorded very openly so as to allow plenty of room for the sketches and details to be placed opposite them. In addition to the notes for the size of the workings the surveyor should note the peculiarities of the ore face, as "8-foot lean ore," "3-foot rich ore," etc., and if the workings pass from one kind of rock to another, he should note the point of change. By observing these geological features as the mining progresses, a vast amount of geological data is accumulated and accurately located for future study. The cost of taking this, while running a survey, is very small, but it might be very costly to get it at a later time. Many of the features would not be observed after the walls were covered with smoke and dirt, and where the mine was flooded or the timbering had rotted and the ground had caved in, they could not be obtained at all. A few of these geological notes are given in Fig. 34. The collection of geological data is discussed more fully in Chapter XIV.

The details can be determined by the methods that are common on surface surveys, namely, by distances, by angles, and by radiating sights. The work of collecting the data, however, is complicated by the peculiarities of mining and by the darkness.

Details by Distances.—Details may be obtained first, by offsets taken normal to the main tape stretched between known points, or, second, by tape surveys where a network of triangles is built up by measuring their sides. Fig. 31 represents a drift that has been traversed, and which will be used to illustrate the processes of determining the details by tape measurements.

The offset method is especially applicable to narrow workings, as drifts, tunnels, or gangways. The main tape is stretched along the floor from one station point to the next, and at intervals along it the offsets are measured to the walls on each side. If the passageway is fairly regular, the offset may be taken at intervals of 25 ft. If it is irregular, the offsets should be taken at every important change in the direction of either wall. The distances along the tape at which the offsets are taken and the length of the offset are noted to the nearest foot and are recorded on a sketch as shown in Fig. 32. This sketch includes all the field notes for the details between Sta. 42 and 44 of the drift.

The sketch made in the field is often a very poor picture of the workings but it serves to show what parts are to be connected and gives information in a brief graphic form that would require considerable writing to describe. The center line of the page is used as the base line of the offsets, hence when there are large angles between the various traverse lines, each line must be sketched by itself and no attempt be made to draw a continuous sketch with the parts in their proper relation to one another. If the sketches of the details for two traverse lines are connected and these traverse lines make an angle at the station, the sketch will be much distorted and there may be some doubt as to the direction of an offset which has been taken at the angle point, but if the sketches are separated, the offset is evidently normal to the line to which it is attached. Each station then shows twice on the same page, but with a gap between the two positions. The fact that the walls are continuous across this gap and that they connect the last points on the adjoining sketches is indicated by the dotted lines connecting these points. The traverse when it is plotted, will be bent at each station to correspond with the horizontal angles, and the walls will swing around into their correct position. The sketch should be started at the bottom of the page and be built upward, so that it will lie in the hand in a position parallel to the workings that it represents.

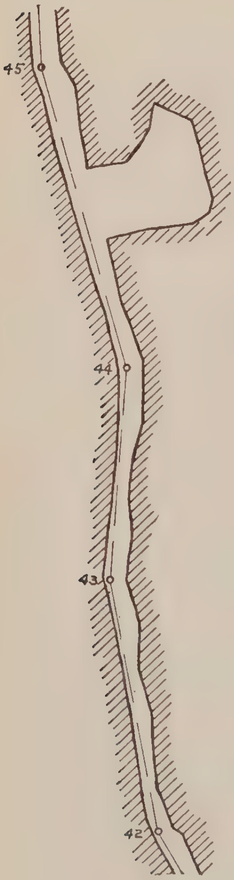


Fig. 31.—Plan of drift, to be surveyed for details.

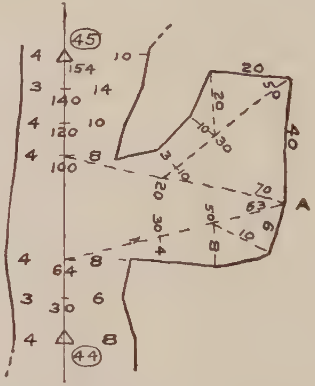


Fig 33.—Field notes of tape survey.

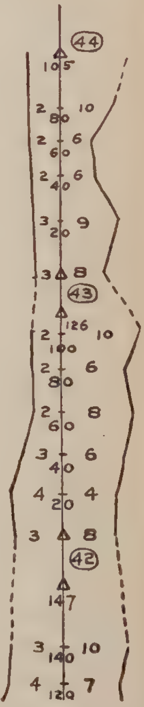


Fig. 32.—Field notes of offsets.

The "Field Notes" at the end of this chapter give many illustrations of the details of levels and narrow places that were taken by offsets, and on pages 4 and 6, the details of parts behind a projection were obtained by stretching a base line between two points that had previously been located and by taking offsets from this base. The two points that form the ends of such an auxiliary base line should be marked with chalk, candle butts, or some foreign object when first located, so that they can be identified when the taping survey is made.

If the survey is to be plotted to a scale of 50 ft. to the inch, a heavy pencil line will be a foot wide on the map, and hence the distances along the tape and the length of the offsets need only be noted to the nearest foot, and if the offsets are 25 ft. apart in the field they will be only $\frac{1}{2}$ in. apart on such a map. If the scale is smaller, less offsets are needed, and their length within 2 or 3 ft. is sufficiently close. Often short offsets for small scale maps can be estimated by the eye, but such practice must be limited to lines that are short enough for both ends to be seen clearly, as lengths are very deceptive in the dark. For accurate work, to be plotted on a large scale, the distances should be measured to the nearest half or even tenth of a foot.

The points that are located should be average points for their portion of the wall, and should be chosen often enough so that when plotted and joined by straight lines they will give a representative outline of the parts surveyed. The points chosen on the walls should be about 3 ft. above the floor, so as to get the widest part of the passage, and so as to avoid the rock left in the corner where the floor and wall join. If the passage is to be timbered, the size of the excavation should be obtained before the lagging is put in, or if it is already in place, the position of the walls may be determined by rods pushed through the lagging at intervals.

A moderate size for a survey party is three men, and such a party might take offsets in several ways. If the floor is uniform, the main tape could be stretched along it from one station to the other, and then be laid down, two men could measure the offsets with a short tape without moving the main tape, and the chief could direct the work and take the notes. If the floor is irregular, one man could hold the zero of the main tape at the rear station, a light could be placed on the forward station, and the chief and other man could measure the offsets; at each offset, the main tape could be pulled tight and the rear man could line it in by the light on the forward station. If the workings were narrow, the two men could hold the main tape and the chief could estimate the offsets with his eye, or measure them with a pole and note them. In ordinary traverse work, the survey party completes the instrument work at a station, and then takes the details for the space between the instrument and the forward station before moving up.

If the details of an extensive mine are to be obtained by measuring the offsets from the traverse lines along the passages where a large area is to be surveyed, it would be economical to perform the instrument work first and then follow with a separate corps to take the details. Such a corps might well consist of five men, and would work as follows, two men would stretch and hold the main tape between two survey points, two men would measure the offsets to points on the walls at intervals, and the chief would direct the work of the offset men and keep the notes. Such a corps would take details with great rapidity as each man would do only one kind of work, and there would be little occasion for one man to wait for another.

The application of the offset method of taking details, as applied to coal mining, is given in Chapter VII.

In all offset work the distance between the end stations should be noted as a check on the distance. If the main tape is on an incline the length will be longer than the horizontal distance to be plotted on the map and all the distances along the tape will have to be reduced proportionately.

The offsets measured from the tape to the walls only serve for a horizontal plan of the workings. In order to plot a vertical longitudinal section of a mine, similar offsets are needed to the roof. These vertical offsets would be obtained by measuring at known intervals from the track to the roof, if the track was carefully laid to grade, or the work could be done with a level, taking rod-sights *above* the line of sight at known intervals with the zero end of the rod turned upward.

Tape surveys are useful in getting important details and for working at some distance from the traverse lines. A simple case is that of locating a point by two measurements from two known points on the main tape. The angle of these lines with the tape is of no importance, as the lines will be plotted in the same manner as used in laying out a triangle when the length of its three sides are known. Other triangles can be built on the sides of the first triangle and the system can thus be extended so as to make quite an extensive but rough survey. The sides of tape surveys should be measured horizontally as there is no way of reducing the sides to the horizontal if they are made on the incline. These tape surveys will be referred to again in Chapter IX. The details can be obtained by offsets from the sides of the triangles. Fig. 33 shows the field notes and method of making such a tape survey for the drift between Sta. 44 and 45.

Tape surveys can be often used to advantage in determining some of the details even when the bulk of the work is done by radiating sights, as shown in Fig. 34, where the parts hidden by the pillar are gotten by taping instead of making another set-up.

Details by Angles.—Points may be located by two intersecting sights but the method has a narrower application in a mine than on surface, owing to the uncertainty of being able to see a point from the second station and to the necessity of having a man take a light to the point in order to get the sight. When a man has to visit a point it is simpler to have him carry a tape with him and to locate the point by a radiating sight. The use of intersecting sights would be limited, then, to the location of the few points to which a light could be carried but to which the tape could not be gotten, or of the points that are inaccessible but that could be illuminated by a beam of light as those on the far side of a pool of water.

Details by Radiating Sights.—This method of getting details is used where the workings have a room-like form. The direction of the line from the station to a point is taken by the transit and its length is taped. If the point is much above or below the instrument, the vertical angle is also read and the horizontal length of the taping is calculated in the office and used in the plotting.

The notes are conveniently recorded on a sketch, on the right-hand page of the field book, opposite the corresponding traverse notes. This sketch gives a rough outline of the workings and also shows which points are to be connected when plotting the map. Such a sketch with its field notes is given in Fig. 34. The character of the various observations is indicated by the manner in which they are recorded, thus the horizontal angles show the degree mark and have a dash between the degrees and the minutes; the vertical angles are prefixed by a plus or by a

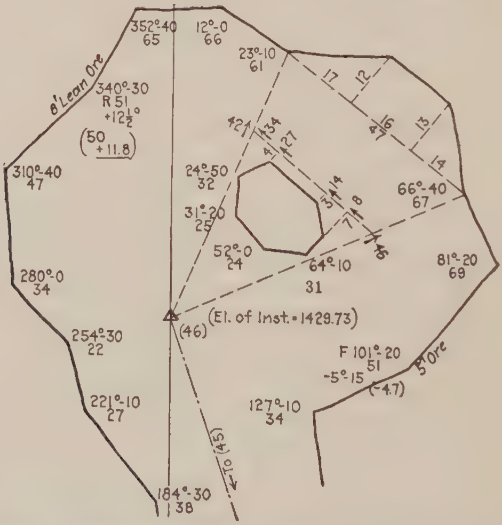


FIG. 34.—Field notes of radiating sights. Angles were measured by azimuths, the top of the page being approximately north. Figures in brackets were added in the office in red ink.

minus sign and are written as degrees and minutes or as degrees and fractions; and the distances are noted as whole numbers or as a number and decimal. In the office, the inclined distances are reduced to horizontal ones, and the latter are noted in red ink on the notes; they are inclosed in brackets in the sketches given here. These horizontal distances are the ones used in plotting. The ink used in making office entries in the note books must be waterproof so as not to blot if the book gets wet.

Other examples of this method of determining the details are given in the "Field Notes" at the end of this chapter, where the sketches are kept opposite the traverse notes. They illustrate the method of recording the observations under various conditions and show the use of tape surveys in connection with the radiating sights.

Where the difference between the inclined taping and the horizontal distance to a point is less than a foot, it is unnecessary to measure the vertical angle or to reduce the taping to the horizontal, as the details cannot be plotted closer than a foot on maps of the ordinary scale of 50 ft. or more to the inch. In no case is it necessary to read the angle closer than $\frac{1}{4}$°, unless heights are to be determined.

The data for determining the elevations of points on both the floor and roof should be taken at frequent intervals so as to determine and record the form of the ore deposit. These elevations can be deduced from the vertical angles and the distances and for this purpose some vertical angles should be read even when not wanted to give the horizontal distances. The highest and lowest parts of the ore body should be noted. The vertical heights of points are calculated at the same time that the inclined distances are reduced to the horizontal and are noted in the field book in red ink. They are shown in brackets in Fig. 34 and in the "Field Notes." They are preceded by plus or minus signs.

The method used for determining the direction of radiating sights depends on the method of angle reading used on the traverse. If the horizontal angles of the traverse were read by azimuths, then the azimuths of the sights would be taken; this is the method shown in Fig. 34. If the horizontal angles between courses were read either once or by repetition, the angle made by the radiating sight with the back course would be measured. This is the method shown in the "Field Notes." There is no need of reading the angles for radiating sights closer than 10 minutes as that is as close as can be plotted even on large scale maps.

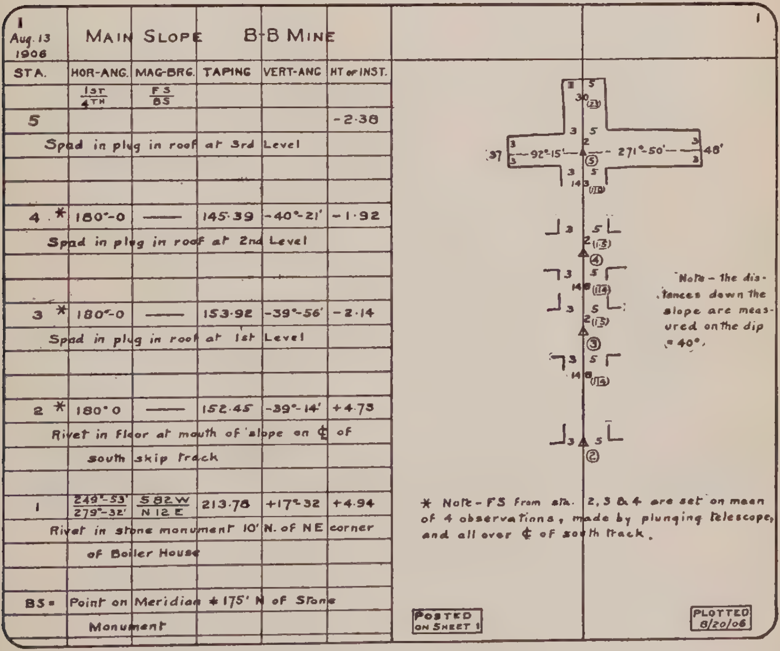
In taking radiating sights, three men give the most expeditious work. One man holds the zero of the tape and his light on the point which is to be located, the instrument man points his telescope on the light; when he has his transit set the assistant at his side pulls the tape taut measuring the distance. A quick release of the strain notifies the other man that the distance has been measured and a swing of a light at the instrument notifies him to move to the next point. Meanwhile the transitman reads and records his angle, then notes the distance told him by the assistant at his side and makes a sketch showing the sequence of the points and resembling the mine workings in a general way. If only two men try to do this work, the chief has to do all the work at the transit and alternately pick up and lay down the tape, as he cannot hold the tape while operating the instrument or recording notes, and the other man cannot move until some one holds the tape at the transit end in order to keep it taut and lift it over obstructions. Consequently the work proceeds slowly and is tiresome and uneconomical.

FIG. 35 TO 45. FIELD NOTES OF THE SURVEYS OF THE BLANK-BLANK MINE MADE BY THE THREE TRIPOD METHOD.

The directions of the radiating sights are noted as angles from the back courses which are taken as zero.

These "Field Notes" have been used in this book to illustrate the methods of carrying on a survey as follows:

In Chapter III, under traversing by the three tripod method;
In Chapter IV, under the collecting of the details of workings;
In Chapter V, under the calculating of the results of traverses;
In Chapter VI, under the plotting of traverses and details on maps.



I Aug. 13 1906	MAIN SLOPE		B-B MINE		
STA.	HOR-ANG.	MAG-BRG.	TAPING	VERT-ANG	HT of INST.
	1ST / 4TH	FS / BS			
5					-2·38
Spad in plug in roof at 3rd Level					
4 *	180°-0	——	145·39	-40°-21′	-1·92
Spad in plug in roof at 2nd Level					
3 *	180°-0	——	153·92	-39°-56′	-2·14
Spad in plug in roof at 1st Level					
2 *	180°0	——	152·45	-39°-14′	+4·73
Rivet in floor at mouth of slope on ℄ of					
	south skip track				
1	249°-53′ / 279°-32′	S 82 W / N 12 E	213·78	+17°-32	+4·94
Rivet in stone monument 10′ N. of NE corner					
	of Boiler House				
BS =	Point on Meridian ± 175′ N of Stone				
	Monument				

Note – the distances down the slope are measured on the dip = 40°.

* Note – FS from sta. 2, 3 & 4 are set on mean of 4 observations, made by plunging telescope, and all over ℄ of south track.

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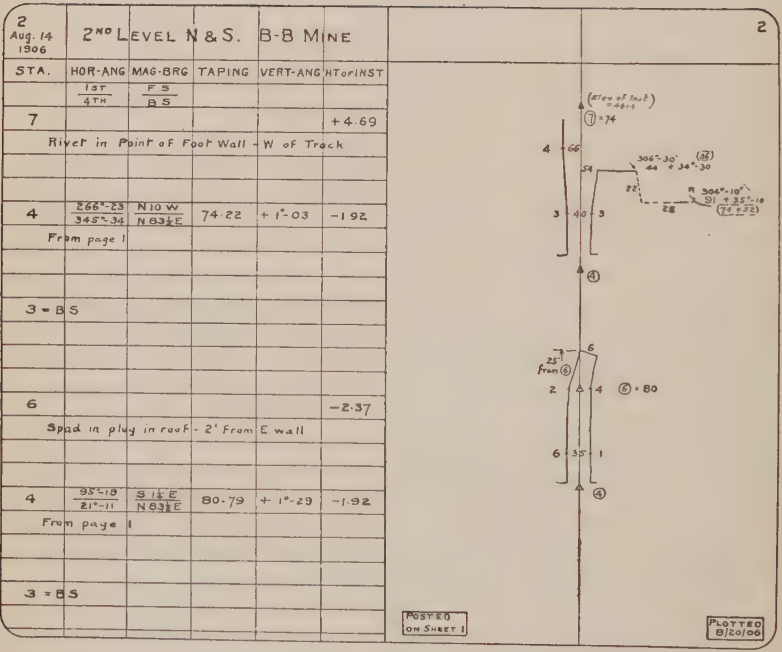
PLOTTED 8/20/06

FIG. 35.—Field Notes. Page 1.



2
Aug. 14
1906

2ND LEVEL N & S. B-B MINE

STA.	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT of INST
	1ST 4TH	F S B S			
7					+4.69
Rivet in Point of Foot Wall - W of Track					
4	266°-23 345°-34	N 10 W N 83½ E	74.22	+ 1°-03	-1 92
From page 1					
3 = BS					
6					-2.37
Spad in plug in roof - 2' From E wall					
4	95°-18 21°-11	S 1¼ E N 83½ E	80.79	+ 1°-29	-1.92
From page 1					
3 = BS					

2

(Elev of Inst = 4.61)
⑦ = 74
4
66
54
306°-30'
44
+ 34°-30
(34)
22
R 304°-10'
91
+ 35°-10
28
(74 + 52)
3
40
3
④
6
25'
from ⑥
2
4
⑥ = 80
6
35
1
④

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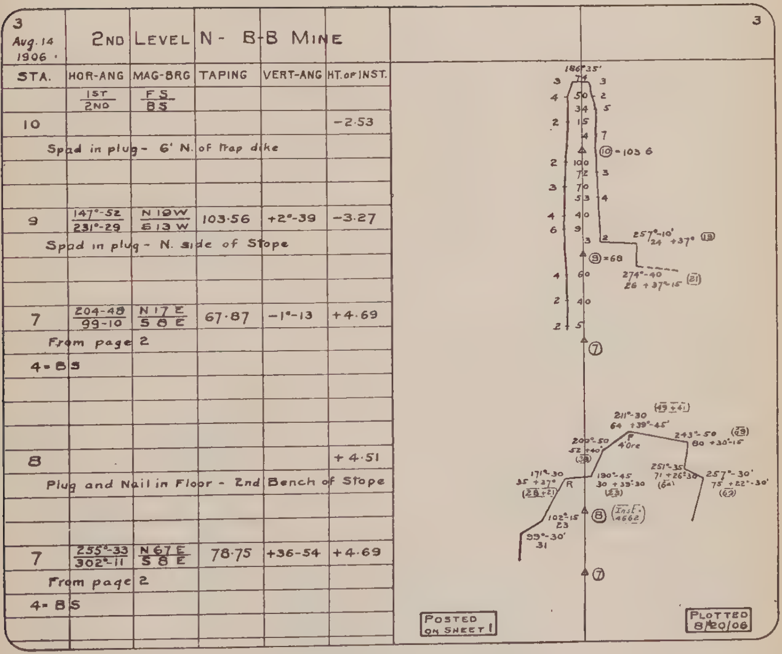
FIG. 36.—Field Notes. Page 2.



3

Aug. 14
1906 ·

2ND LEVEL N - B-B MINE

STA.	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. OF INST.
	1ST 2ND	F S B S			
10					−2·53
Spad in plug - 6′ N. of Trap dike					
9	147°-52 231°-29	N 19 W S 13 W	103·56	+2°-39	−3·27
Spad in plug - N. side of Stope					
7	204-48 99-10	N 17 E S 8 E	67·87	−1°-13	+4·69
From page 2					
4-BS					
8					+ 4·51
Plug and Nail in Floor - 2nd Bench of Stope					
7	255°-33 302°-11	N 67 E S 8 E	78·75	+36-54	+4·69
From page 2					
4- BS					

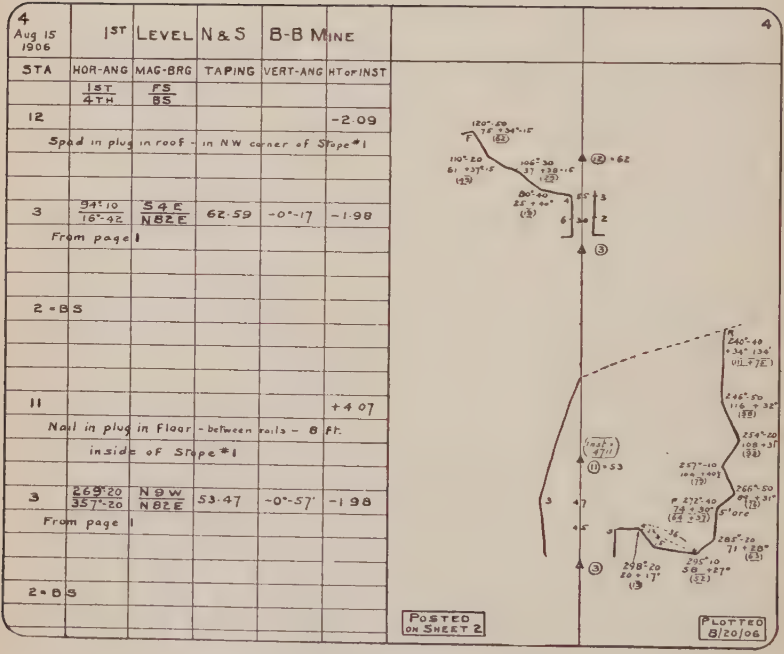
3

186°35′
74
3
3
4
50
2
34
5
2
15
7
4
⑩ = 103 6
2
100
72
3
3
70
53
4
4
40
6
9
3
2
257°-10′
24 +37°
(13)
⑨ = 68
4
60
274°-40
26 +37°-15
(21)
2
40
2
5
⑦
211°-30
64 +39°-45′
(49 +41)
200°-50
52 +40°
(38)
F
4′ Ore
243°-50
80 +30°-15
(69)
171°-30
35 +27°
(28 +21)
R
190°-45
30 +33°-30
(23)
251°-35
71 +26°-30
(64)
257°-30′
75 +22°-30′
(63)
102°-15
23
⑧
(Inst.
4662)
99°-30′
31
⑦

POSTED
ON SHEET 1

PLOTTED
8/20/06

FIG. 37.—Field Notes. Page 3.



4 Aug 15 1906 — 1st Level N & S — B-B Mine — 4

STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT of INST
	1ST 4TH	FS BS			
12					-2.09
Spad in plug in roof - in NW corner of Stope #1					
3	94°-10 16°-42	S 4 E N 82 E	62.59	-0°-17	-1.98
From page 1					
2 - BS					
11					+4 07
Nail in plug in Floor - between rails - 8 ft.					
inside of Stope #1					
3	269°-20 357°-20	N 9 W N 82 E	53.47	-0°-57'	-1 98
From page 1					
2 - BS					

F
120°-50
75 +34°-15
(62)
110°-20
61 +37°-15
(23)
106°-30
37 +38°-15
(29)
80°-40
25 +40°
(19)
⑫ - 62
5.5
3
4
6
3.0
2
③
R
240°-40
+34° 134'
(111 +75)
246°-50
116 +32°
(98)
254°-20
108 +31°
(92)
Inst = 4.7
⑪ - 53
257°-10
104 +40½
(79)
266°-50
89 +31°
(76)
P 272°-40
74 +30°
(64 +37)
5' ore
3
4.7
4.5
5
36
285°-20
71 +28°
(63)
③
298°-20
20 +17°
(19)
295°-10
58 +27°
(52)

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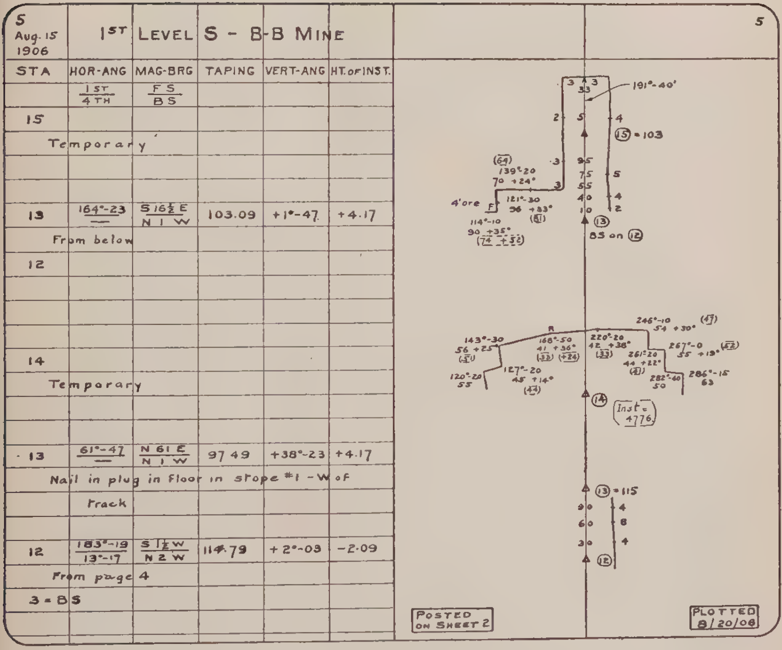
FIG. 38.—Field Notes. Page 4.



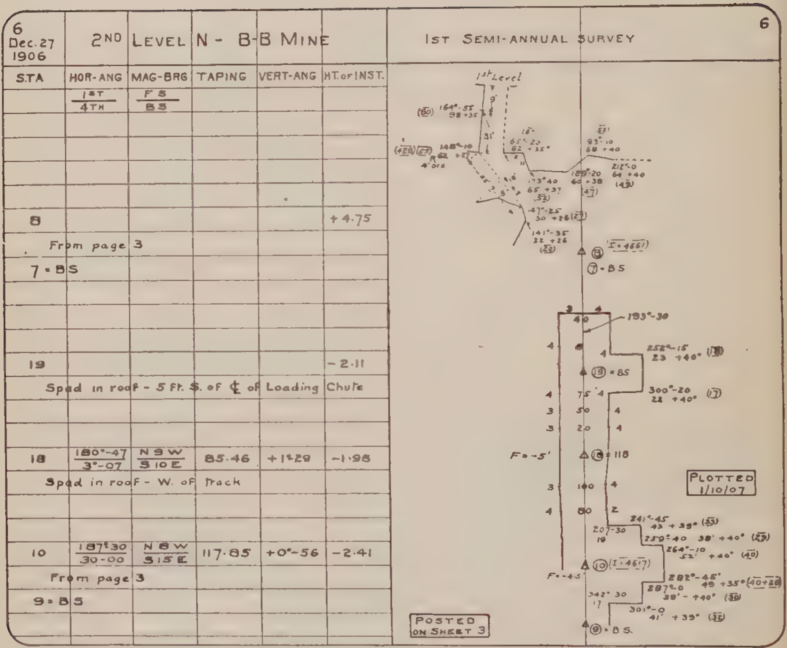
5
Aug. 15
1906

1ST LEVEL S - B-B MINE

STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. OF INST.
	1ST / 4TH	F S / B S			
15					
Temporary					
13	164°-23 / —	S 16½ E / N 1 W	103.09	+1°-47	+4.17
From below					
12					
14					
Temporary					
13	61°-47 / —	N 61 E / N 1 W	97 49	+38°-23	+4.17
Nail in plug in floor in stope #1 - W of track					
12	183°-19 / 13°-17	S 1½ W / N 2 W	114.79	+2°-03	-2.09
From page 4					
3 = BS					

5
191°-40'
3 3
33
2
5
4
⑮ = 103
(64)
139°-20
70 +24°
3
95
75
55
40
10
5
4
2
4'ore
F
121°-30
96 +33°
(81)
114°-10
90 +35°
(74 +52)
⑬
BS on ⑫
R
246°-10
54 +30°
(47)
143°-30
56 +25°
(51)
168°-50
41 +36°
(33) (+24)
220°-20
42 +38°
(33)
267°-0
55 +19°
(52)
261°-20
44 +22°
(41)
120°-20
55
127°-20
45 +14°
(43)
282°-40
50
286°-15
63
⑭
Inst = 4776
⑬ = 115
90
60
30
4
8
4
⑫
POSTED ON SHEET 2
PLOTTED 8/20/06

FIG. 39.—Field Notes. Page 5.



6 Dec. 27 1906 | 2ND LEVEL N - B-B MINE | 1ST SEMI-ANNUAL SURVEY | 6

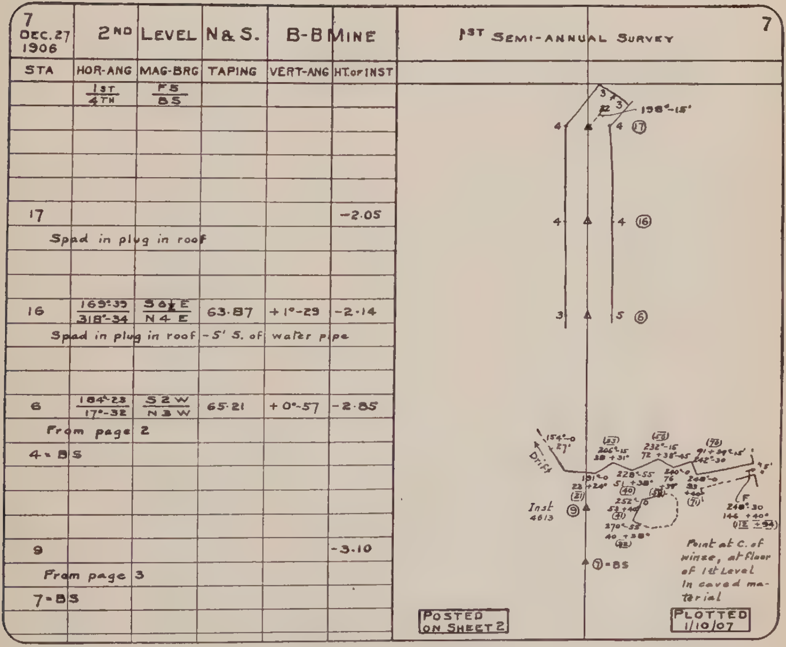
S.TA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. OF INST.
	1ST / 4TH	F S / B S			
8					+ 4.75
From page 3					
7 = BS					
19					− 2.11
Spad in roof - 5 ft. S. of ℄ of Loading Chute					
18	180°-47 / 3°-07	N 9 W / S 10 E	85.46	+ 1°28	− 1.98
Spad in roof - W. of track					
10	187°30 / 30-00	N 8 W / S 15 E	117.85	+ 0°-56	− 2.41
From page 3					
9 = BS					

POSTED ON SHEET 3

PLOTTED 1/10/07

1st Level
9'
31'
164°-55 98 +35
148°-10 62 +27
4' ore
65°-20 82 +35°
93°-10 68 +40
212°-0 64 +40
189°-20 60 +38
173°40 65 +37
147°-25 30 +26
141°-35 22 +26
(I = 4661)
⑧
⑦ = BS
193°-30
40
252°-15 23 +40°
⑲ = BS
300°-20 22 +40°
75
50
20
F = -5'
⑱ = 118
100
80
241°-45 43 +39°
207-30 19
259°-40 38' +40°
264°-10 52' +40°
⑩ (I = 4617)
F = -4.5
282°-45' 49 +35°
287°-0 38' - +40°
342° 30 17
301°-0 41' +39°
⑨ = BS.

FIG. 40.—Field Notes. Page 6.



7 DEC. 27 1906	2ND	LEVEL	N & S.	B-B	MINE
STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. OF INST
	1ST 4TH	FS BS			
17					−2.05
Spad in plug in roof					
16	169°-35 318°-34	S 6½ E N 4 E	63.87	+1°-29	−2.14
Spad in plug in roof			−5′ S. of	water pipe	
6	184°-23 17°-32	S 2 W N 3 W	65.21	+0°-57	−2.85
From page 2					
4 = BS					
9					−3.10
From page 3					
7 = BS					

1ST SEMI-ANNUAL SURVEY 7

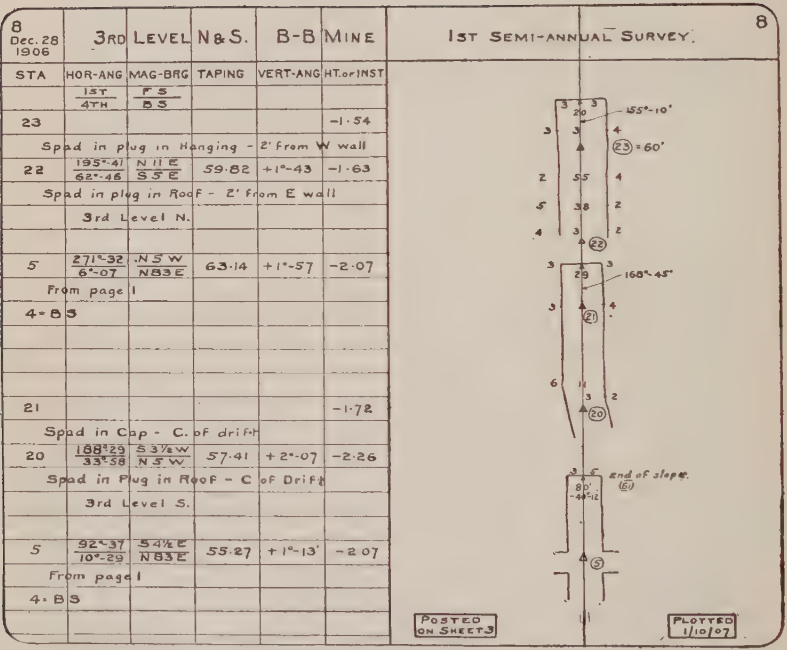
3
3
2
3
198°-15′
4
4
⑰
4
4
⑯
3
5
⑥
154°-0
27′
Drift
(33)
206°-15
38 + 31°
(58)
232°-16
72 + 38°-45
(78)
91 + 34°-15′
242°-30
5′
191°-0
22 + 24°
(21)
228°-55
51 + 38°
(40)
240°-0
76
+ 38°
(51)
248°-0
33
+ 40°
(71)
252°-0
53 + 40°
(41)
270°-55
40 + 38°
(92)
F
240°-30
146 + 40°
(112 + 94)
Inst
4613
⑨
⑦ = BS

Point at C. of winze, at floor of 1st Level In caved material

POSTED ON SHEET 2

PLOTTED 1/10/07

FIG. 41.—Field Notes. Page 7.



8
Dec. 28
1906

3RD LEVEL N & S. B-B MINE

STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. of INST
	1ST 4TH	FS BS			
23					−1·54
Spad in plug in Hanging – 2′ from W wall					
22	195°-41 62°-46	N 11 E S 5 E	59·82	+1°-43	−1·63
Spad in plug in Roof – 2′ from E wall					
	3rd Level N.				
5	271°-32 6°-07	N 5 W N 83 E	63·14	+1°-57	−2·07
From page 1					
4 = BS					
21					−1·72
Spad in Cap – C. of drift					
20	188°-29 33°-58	S 3½ W N 5 W	57·41	+2°-07	−2·26
Spad in Plug in Roof – C of Drift					
	3rd Level S.				
5	92°-37 10°-29	S 4½ E N 83 E	55·27	+1°-13′	−2·07
From page 1					
4 - BS					

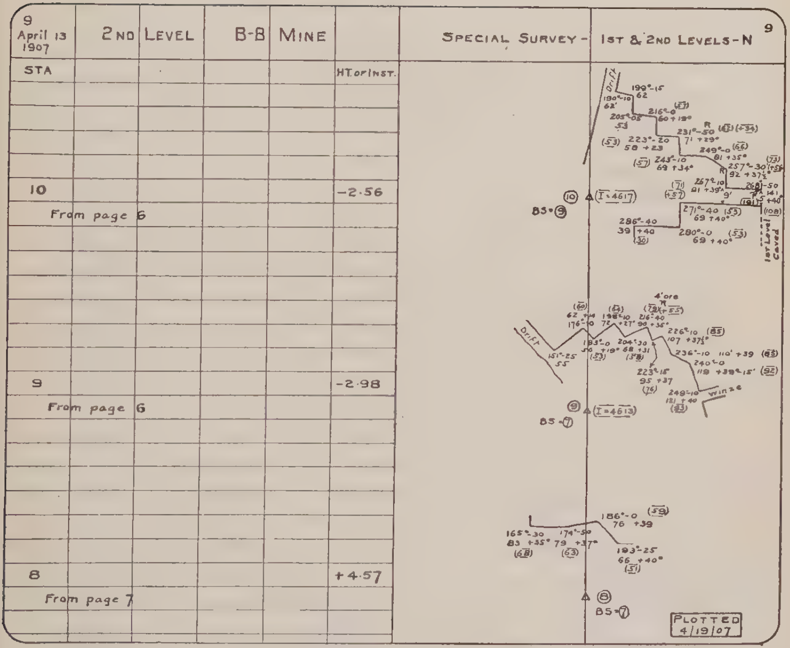
8

1ST SEMI-ANNUAL SURVEY.

POSTED ON SHEET 3

PLOTTED 1/10/07

FIG. 42.—Field Notes. Page 8.

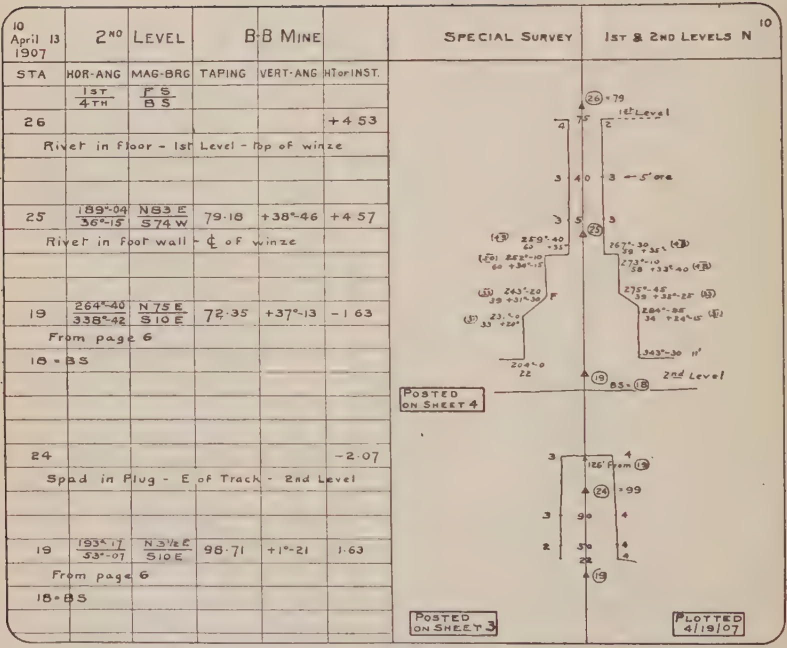


9 April 13 1907	2ND	LEVEL	B-B	MINE	
STA					HT. or INST.
10					−2.56
From page 6					
9					−2.98
From page 6					
8					+4.57
From page 7					

SPECIAL SURVEY - 1ST & 2ND LEVELS - N 9

Drift
199°-15
62
190°-10
62'
216°-0
(57)
205°-05
53
60 +19°
R
231°-50
(63) (+34)
(53)
223°-20
58 +23
71 +29°
249°-0
(66)
81 +35°
(57)
245°-10
69 +34°
(73)
257°-30' (+56)
92 +37½°
(71)
(+57)
267°-10
81 +39°
9'
268°-50
141
+40
(191)
(108)
10
(I=4617)
BS=9
271°-40
69 +40°
(53)
286°-40
39
+40
(30)
280°-0
69 +40°
(53)
1st Level Caved
4' ore
(60)
62 +14
176°-10
(64)
198°-10
72 +27°
(79)(+55)
216°-40
90 +35°
226°-10
107 +37½°
(85)
Drift
151°-25
55
183°-0
56 +19°
(53)
204°-30
68 +31
(58)
236°-10
110' +39
(85)
240°-0
119 +38°-15'
(92)
223°-15
95 +37
(76)
249°-10
121 +40
(93)
Winze
9
(I=4613)
BS=7
186°-0
76 +39
(59)
165°-30
83 +35°
(68)
174°-50
79 +37°
(63)
193°-25
66 +40°
(51)
8
BS=7
PLOTTED
4/19/07

FIG. 43.—Field Notes. Page 9.



10
April 13
1907

2ND LEVEL B-B MINE

STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT of INST.
	1ST 4TH	FS BS			
26					+4 53
Rivet in floor - 1st Level - Top of winze					
25	189°-04 36°-15	N83 E S74 W	79·18	+38°-46	+4 57
Rivet in foot wall - ℄ of winze					
19	264°-40 338°-42	N 75 E S 10 E	72·35	+37°-13	-1 63
From page 6					
18 = BS					
24					-2·07
Spad in Plug - E of Track - 2nd Level					
19	193°-17 53°-07	N 3½ E S10E	98·71	+1°-21	1·63
From page 6					
18 = BS					

SPECIAL SURVEY

1ST & 2ND LEVELS N

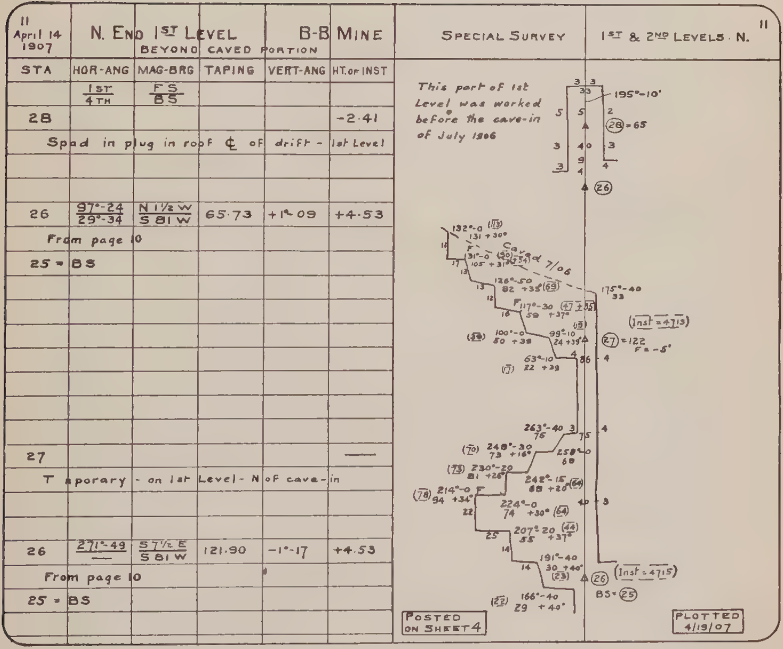
10

POSTED
ON SHEET 4

POSTED
ON SHEET 3

PLOTTED
4/19/07

FIG. 44.—Field Notes. Page 10.



11
April 14
1907

N. END 1ST LEVEL B-B MINE
BEYOND CAVED PORTION

STA	HOR-ANG	MAG-BRG	TAPING	VERT-ANG	HT. OF INST
	1ST 4TH	FS BS			
28					-2·41
Spad in plug in roof ℄ of drift - 1st Level					
26	97°-24 29°-34	N 1½ W S 81 W	65·73	+1°-09	+4·53
From page 10					
25 = BS					
27					—
Temporary - on 1st Level - N of cave-in					
26	271°-49 —	S 7½ E S 81 W	121·90	-1°-17	+4·53
From page 10					
25 = BS					

SPECIAL SURVEY 1ST & 2ND LEVELS. N. 11

This part of 1st Level was worked before the cave-in of July 1906

POSTED ON SHEET 4

PLOTTED 4/19/07

FIG. 45.—Field Notes. Page 11.

CHAPTER V

TRAVERSE CALCULATIONS

The field notes are seldom in such a form that they can be plotted without some calculations; the amount of calculations depends on the method of plotting that is to be used. The method of plotting by coordinates is the most accurate one and affords many chances to detect errors as the work progresses. It should be used for all important surveys.

The calculation of a traverse for coordinate plotting may be divided into five steps:

1. Verifying of the field notes and posting them on the "Survey Record."
2. Reducing the horizontal angles to bearings.
3. Correcting the tapings for temperature and sag and reducing them to horizontal distances.
4. Calculating the latitude and departure of the station points.
5. Determining the elevation of the station points.

The form of the calculations depends on the method of surveying that was used, although the principle remains the same and the above steps must be taken in most cases.

CALCULATIONS FOR A THREE TRIPOD SURVEY

The "Field Notes," Figs. 35 to 45, at the end of Chapter IV, for the survey of the Blank-Blank Mine, will be used as the data for the calculations which will be worked out step by step and the final results will be entered in the "Survey Record" at the end of this chapter.

1. **Verifying and Posting of the Field Notes.**—The field notes should be carefully inspected and the various observations be compared before any use is made of the notes, in order to detect

any errors that may have occurred in the field work. The differences of the magnetic bearings are figured, as described on page 15, and compared with the first angle read by the transit to detect gross errors in the latter. The mean horizontal angle is obtained by dividing the last reading by the number of observations in the set, it is compared with the first reading and if it agrees, it is posted in Col. 2 of the "Survey Record"; it is sometimes also noted in the field book. The various readings of the vertical angle are compared if it has been observed more than once, and the mean is posted in Col. 8. The taped distance is posted in Col. 5; if more than one measurement has been taken, the mean of them is entered. The height of the instrument is posted in Col. 19. All of these entries are made on the line opposite the station at which they were observed. The entries should be made first in pencil, then, after they have been checked, they should be inked in and form the basis for the subsequent calculations. It is also necessary to post from previous information the azimuth of the course from the backsight to the instrument station in Col. 3, and the three coordinates of the first instrument point in Col. 12, 15, and 20. Often the azimuth of the first course and the coordinates of the initial point of the survey are fixed arbitrarily, but having been so fixed, must never be changed. In the example here given, the direction of the meridian through Sta. 1, and the elevation of Sta. 1 were known and the latitude and departure of Sta. 1 were both fixed as zero. The information that is obtained from some other source than the field book or calculations resulting therefrom is underlined on the "Survey Record," and sometimes a cross reference is entered showing its origin. The station numbers are entered in Col. 1 and, for convenience in using the sheets, are repeated in Col. 21.

2. **Reducing the Horizontal Angles to Bearings.**—The azimuth of each course is found from the azimuth of the previous course and the horizontal angles between courses, see page 17 and entered in Col. 3. The bearing is then calculated and entered in Col. 4. The azimuth and bearing entered opposite any station give the direction of the forward course from that station; thus,

the entries opposite Sta. 9 of azimuth = 328°-56 $\frac{1}{4}'$ and bearing = N. 31°-04′ W. give the direction of the line from Sta. 9 to Sta. 10. The fractions obtained in calculating the mean horizontal angles are retained in calculating the azimuths in order to check the closure of the angles of the traverse, but the bearings need only be noted to the nearest minute, as the errors introduced by dropping the fractions of a minute are negligible.

3. **Correcting and Reducing the Tapings.**—The tape measurements are sometimes corrected for temperature, are often corrected for sag, and when inclined must be reduced to the horizontal. The temperature correction is small for short distances and the ordinary range of temperatures, and can be omitted except on surveys requiring extreme accuracy. It is neglected in the example here given. The tape hangs in a catenary and so causes the taped distances to be considerably longer than the true distances. The taped distances must therefore be reduced by subtracting a catenary correction as explained on page 24. The correction to be applied is entered in Col. 6 and the corrected taping is entered in Col. 7. The corrected taped distance multiplied by the cosine of the vertical angle, given in Col. 8, gives the horizontal distance which is entered in Col. 9. The taping entered opposite any station is the distance from that station to the next station ahead, thus, the taping opposite Sta. 9 is for the line from Sta. 9 to Sta. 10.

4. **Calculating the Latitudes and Departures.**—The latitude of a forward station with respect to the station occupied by the instrument is the distance that the foresight is north or south of the instrument station, and equals the horizontal distance between stations, Col. 9, multiplied by the cosine of the bearing, Col. 4, and similarly the departure of the forward station with respect to the station occupied by the instrument, is the distance that the foresight is east or west of the instrument station and equals the horizontal distance between stations, Col. 9, multiplied by the sine of the bearing, Col. 4. The latitude and departure is calculated for the forward station from each instrument station and is entered in their respective columns. When a bearing is

north the entry for the latitude goes in Col. 10, and when south it goes in Col. 11. When the bearing is east the entry for the departure goes in Col. 13, and when west it goes in Col. 14. Thus the first four courses having bearings of S. 69°-53′ W., are entered in the south and west columns, that is in Col. 11 and 14. It saves the possibility of making an entry in the wrong column if, before starting to make the entries, a dash is placed in each column of the record sheet in which there is to be no entry. The total latitude and departure of the first instrument station are known, hence, if the latitude and departure of the foresight point are added to them algebraically the sums are the total latitude and departure of the forward station which in turn becomes an instrument station. The total coordinates for every point are found in a similar manner and are posted in Col. 12 and 15. The words "north" or "south" in Col. 12, and the words "east" or "west" in Col. 15 written over the figures indicate the direction of the coordinates from the origin and apply until the word is changed.

In mathematics the coordinates of a point are called the "ordinate" for the vertical and the "abscissa" for the horizontal distances from the origin. These terms are easily confused and are not familiar to many people, so the author prefers the terms common in compass and land surveying and familiar to most people, to wit, latitude and departure. The latitude and departures are preferably based on a true meridian, determined by some astronomical observation, but the method of work is not altered if the meridian is determined by the magnetic needle at some one point, or if the direction of the meridian is fixed arbitrarily. It should, however, be approximately north and south to avoid confusion.

5. Determination of the Elevations.—In the three tripod method, the distance of the foresight signal above or below the transit is found by multiplying the horizontal distance, Col. 9, by the sine of the vertical angle, Col. 8, and when the vertical distance is up corresponding to a plus vertical angle, the product is entered in Col. 16 as a Rise and when it is down, corresponding to a minus vertical angle, the product is entered in Col. 17 as a Fall. The elevation of the first transit point is known from previous surveys. The height of the instrument is measured in the field and posted in Col. 19, it is added algebraically to the elevation of the point in Col. 20 and this gives the elevation of the first instrument which is entered in Col. 18. The elevation of the foresight signal is found by adding algebraically the rise or fall from Col. 16 or 17 to the elevation of the instrument at the first point. The elevation of this foresight signal becomes the elevation of the transit when it is moved up to that station and so is entered in Col. 18 on the next line and opposite the forward station. The elevation of each forward instrument is found successively in a similar manner. The elevation of any point is found by subtracting algebraically the height of the instrument given in Col. 19 from the elevation of the instrument given in Col. 18. The remainder is entered in Col. 20. As "temporary" stations have no station points, the word "temporary" is noted in Col. 20 to explain the omission of the elevation, as at Sta. 14 and 15 on sheet 2.

The Survey Record.—This now contains the original data of the survey, the result of every calculation and the final coordinates in a convenient form. The work can be easily checked when first done and there is a permanent record of every step of the calculations and in case of doubt as to what was done, every operation can be traced and verified. One of the great advantages of coordinate plotting is this chance to make sure that the survey calculations are correct before starting the map. In order to procure the maximum benefit from these checks, the calculation should be made by two independent computers and be compared at intervals. Thus the known data and field notes are posted in the "Survey Record" and the entries checked; then the azimuths, the corrected tapings, the horizontal distances and vertical heights, the latitudes and departures, and, lastly, the elevations of the instruments and of the points are successively calculated by each computer and compared. In calculating, each man should work entirely by himself, taking his own data from the "Survey Record" and carrying it a step further. If a computer must check himself, he should use different methods for the first and for the check calculations as, for example, logarithmic functions for the first time and natural functions or a large traverse table for the second time. A slide rule is valuable for a check against gross errors in the calculations, but is not sufficiently accurate for the calculations proper. The total latitude, departure and elevation of the last station of a traverse can be found by adding up the positive and negative distances in two separate columns and adding them algebraically to the coordinates of the first station. This gives a check on the individual additions made in getting the coordinates of the intermediate stations. These check additions are shown by the small figures in brackets on sheet 1 of the "Survey Record," under the latitude and departure columns.

Different arrangements of the sheets may suggest themselves to surveyors. It can be made somewhat more compact by combining the north and south latitudes in one column and prefixing plus signs to the north ones and minus signs to the south ones and by similarly combining all the departures and all the vertical heights each in a single column using appropriate signs. The author prefers the open form as it is clearer and the totals can be checked by addition. If the angles are read as azimuths, Col. 2 would be omitted. If no corrections for the catenary of the tape are ever made, Col. 6 and 7 would not be needed, and if tapings were made horizontally or reduced to the horizontal in the note book, Col. 5 would be omitted and as no levels could be obtained under these conditions Col. 8 and Col. 16 to 20 would all be unnecessary. While these omissions of columns seem to simplify the record, they do so by reducing the convenience of the sheets and the amount of information obtained from the survey.

If measurements are made with the stadia, as might occur on a surface survey, of a less accurate character, Col. 5 to 9 would be changed to show the addition of the instrument constant and the reduction of the inclined sights to the horizontal by means of stadia tables.

A convenient width for the "Survey Record" is about 21 in. This will allow an average width of 1 in. for the columns, but those that take angles should be a little wider while those for small numbers can be reduced a little in width. Lines that are $\frac{3}{8}$ in. apart give plenty of room and allow for occasional interlining.

The columns of sheet 1 of the "Survey Record" have been numbered for convenience in referring to them, but the numbers are not essential and have been omitted from the other sheets.

CALCULATIONS FOR A PLUMMET SURVEY

With a Plummet Survey, the first four steps in the calculations are the same as for a Three Tripod Survey. These are:

1. Verifying the field notes and posting them on the "Survey Record."
2. Reducing the horizontal angles to bearings.
3. Correcting the tapings for temperature and sag and reducing them to horizontal distances.
4. Calculating the latitudes and departures.

The results of the calculations of the above steps would be entered on the sheets of the "Survey Record" similarly to Col. 1 to 15, as has been fully discussed in the first part of this chapter under the heading of the Three Tripod Survey.

The determination of the elevation is more complicated with a Plummet Survey than with a Three Tripod Survey, but it can be done if proper field observations are made. The form for keeping the field notes of a plummet survey where the elevations are to be obtained from the transit survey was given in Fig. 25 and the essential figures are repeated in Fig. 46 in a condensed form.

The formula for calculating the elevations was given on page 52, viz:

$$\text{Elev. } B = \text{elev. } A + (\pm H.I. \text{ at } A) + (\pm \text{vert. dist.}) - (\pm H.S. \text{ at } B)$$

The results of these calculations would be entered in the last few columns of the "Survey Record" for a plummet survey, and would be arranged as in Fig. 47. These would replace Col. 16 to 20 of the "Survey Record" at the end of the chapter which apply only to the Three Tripod Method.

The elevation of the first point being known, is entered in Col. 16, Fig. 47, opposite its station; the *H.I.* taken at each instrument station is posted from the field notes in Col. 17, it may have a plus or a minus sign; and the *H.S.* of each forward station is posted from the field notes in Col. 22, it may have a plus or a minus sign. The rise and fall are found by multiplying the corrected tapings by the sine of the vertical angles and are entered in Col. 19 and 20.

Station	Horizontal angle	Tape distance	Vertical angle	*H.I.*	*H.S.*
36 =	*B.S.*				
37	199° − 32′	104.29	+25° − 09′	−2.09	+5.07
38	140° − 13′	147.23	−15° − 19′	+4.82	−1.76
39					

FIG. 46.—Field Notes of a Plummet Survey.
(Condensed from Fig. 25)

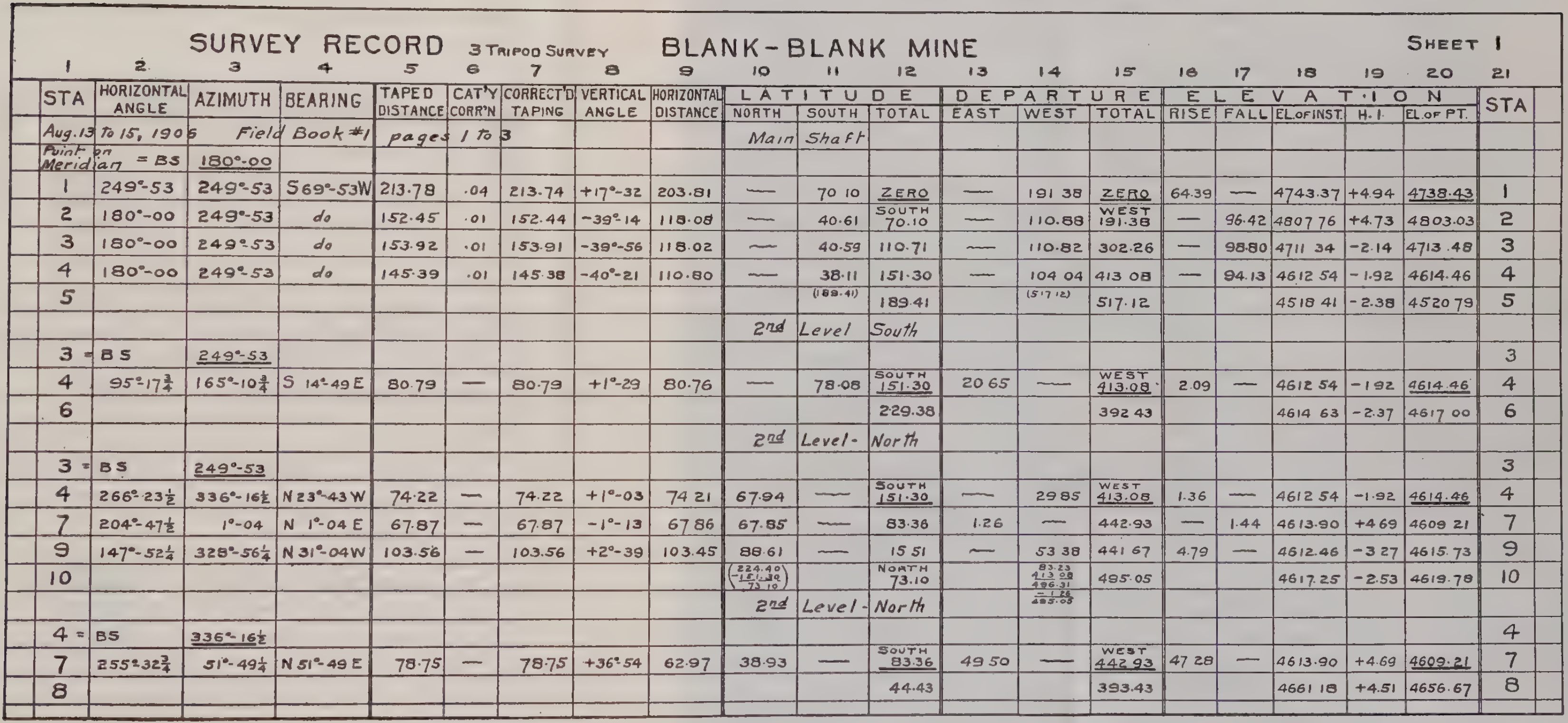
SURVEY RECORD PLUMMET SURVEY

1	2	5	8	16	17	18	19	20	21	22
STA	HORIZONTAL ANGLE	TAPED DISTANCE	VERTICAL ANGLE	ELEVATION						
				EL OF PT.	H.I.	EL. OF INST.	RISE	FALL	EL. OF SIG	H.S.
36	BS									
37	199°-32	104.29	+25°-09	1478.32	-2.09	1476.23	44.32	—	1520.55	+5.07
38	140°-13	147.23	-15°-19	1515.48	+4.82	1520.30	—	38.89	1481.41	-1.76
39				1483.17						

FIG. 47.—Survey Record for Plummet Method. The first 15 columns contain the same information as the corresponding ones in the "Survey Record" for the three tripod method at the end of this chapter and so are omitted in this figure.

The above data substituted in the formula gives the elevation of the point at the forward station, thus the elevation of Sta. 37 = 1478.32 in Col. 16, adding the *H.I.* = −2.09 in Col. 17, gives the elevation of instrument =1476.23 in Col. 18, adding the rise = 44.32 in Col. 19, gives the elevation of signal = 1520.55 in Col. 21, and subtracting the *H.S.* = +5.07 in Col. 22 gives 1515.48 which is the elevation of the forward point, that is, the elevation of point at Sta. 38. This is entered in Col. 16 on the next line opposite Sta. 38, and forms the basis for the calculations for that station

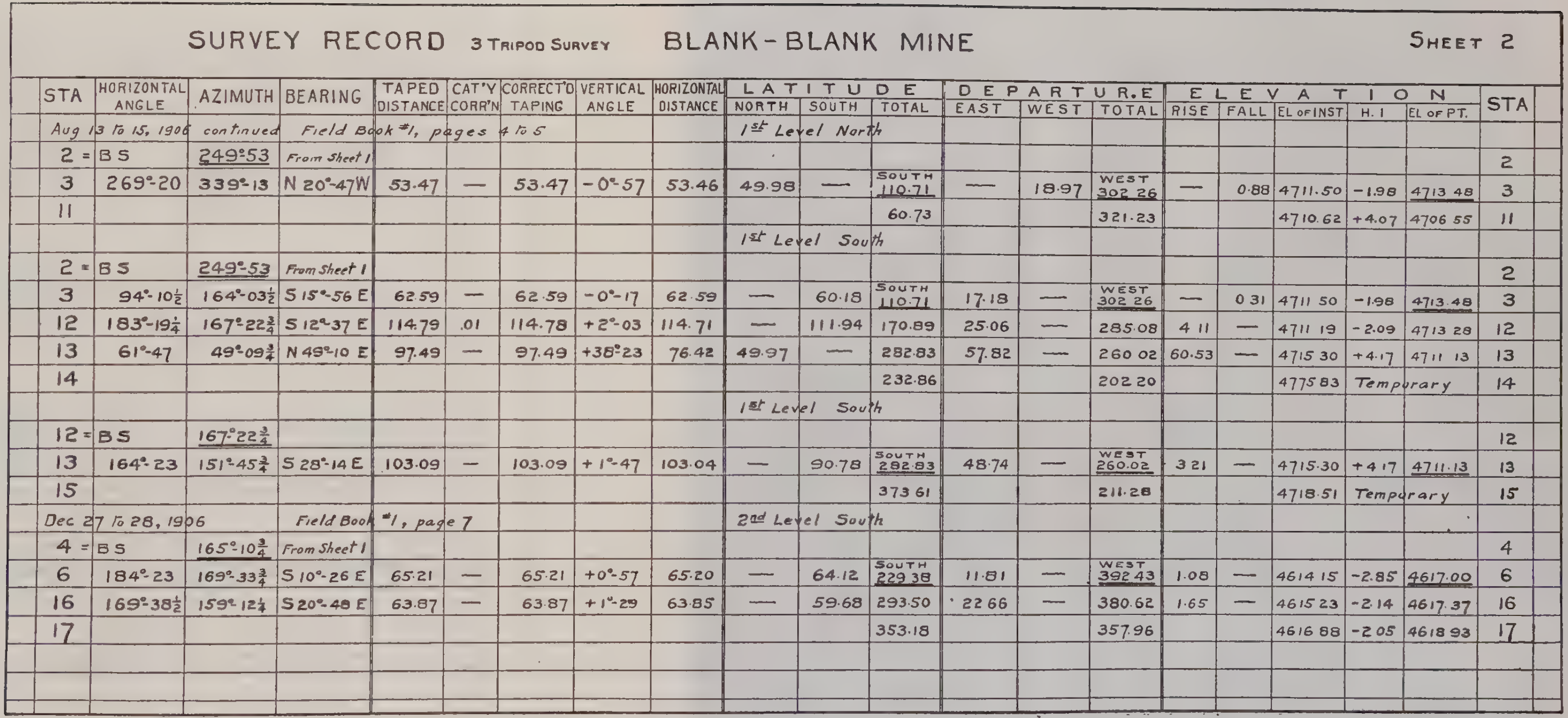
FIGS. 48 TO 51.—SURVEY RECORD OF THE RESULTS OF THE SURVEYS OF THE BLANK-BLANK MINE, MADE BY THE THREE TRIPOD METHOD. These are the results of the calculations based on the "Field Notes" given at the end of Chapter IV.



SURVEY RECORD 3 TRIPOD SURVEY BLANK-BLANK MINE SHEET 1

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
STA	HORIZONTAL ANGLE	AZIMUTH	BEARING	TAPED DISTANCE	CAT'Y CORR'N	CORRECT'D TAPING	VERTICAL ANGLE	HORIZONTAL DISTANCE	LATITUDE			DEPARTURE			ELEVATION					STA
									NORTH	SOUTH	TOTAL	EAST	WEST	TOTAL	RISE	FALL	EL. OF INST.	H. I.	EL. OF PT.	
Aug. 13 To 15, 1906 Field Book #1 pages 1 to 3									Main Shaft											
Point on Meridian = BS		180°-00																		
1	249°-53	249°-53	S 69°-53 W	213.78	.04	213.74	+17°-32	203.81	—	70 10	ZERO	—	191 38	ZERO	64.39	—	4743.37	+4.94	4738.43	1
2	180°-00	249°-53	do	152.45	.01	152.44	−39°-14	118.08	—	40.61	SOUTH 70.10	—	110.88	WEST 191.38	—	96.42	4807 76	+4.73	4803.03	2
3	180°-00	249°-53	do	153.92	.01	153.91	−39°-56	118.02	—	40.59	110.71	—	110.82	302.26	—	98.80	4711 34	−2.14	4713.48	3
4	180°-00	249°-53	do	145.39	.01	145.38	−40°-21	110.80	—	38.11	151.30	—	104 04	413 08	—	94.13	4612 54	−1.92	4614.46	4
5										(189.41)	189.41		(517 12)	517.12			4518 41	−2.38	4520 79	5
									2nd Level South											
3 = BS		249°-53																		3
4	95°-17¾	165°-10¾	S 14°-49 E	80.79	—	80.79	+1°-29	80.76	—	78.08	SOUTH 151.30	20 65	—	WEST 413.08	2.09	—	4612 54	−1 92	4614.46	4
6											229.38			392 43			4614 63	−2.37	4617 00	6
									2nd Level- North											
3 = BS		249°-53																		3
4	266°-23½	336°-16½	N 23°-43 W	74.22	—	74.22	+1°-03	74 21	67.94	—	SOUTH 151.30	—	29 85	WEST 413.08	1.36	—	4612 54	−1.92	4614.46	4
7	204°-47½	1°-04	N 1°-04 E	67.87	—	67.87	−1°-13	67 86	67.85	—	83.36	1.26	—	442.93	—	1.44	4613.90	+4 69	4609 21	7
9	147°-52¼	328°-56¼	N 31°-04 W	103.56	—	103.56	+2°-39	103.45	88.61	—	15 51	—	53 38	441 67	4.79	—	4612.46	−3 27	4615.73	9
10									(224.40 −151.30 73.10)		NORTH 73.10		83.23 413.08 496.31 −1.26 495.05	495.05			4617.25	−2.53	4619.78	10
									2nd Level - North											
4 = BS		336°-16½																		4
7	255°-32¾	51°-49¼	N 51°-49 E	78.75	—	78.75	+36°-54	62.97	38.93	—	SOUTH 83.36	49 50	—	WEST 442 93	47 28	—	4613.90	+4.69	4609.21	7
8											44.43			393.43			4661 18	+4.51	4656.67	8

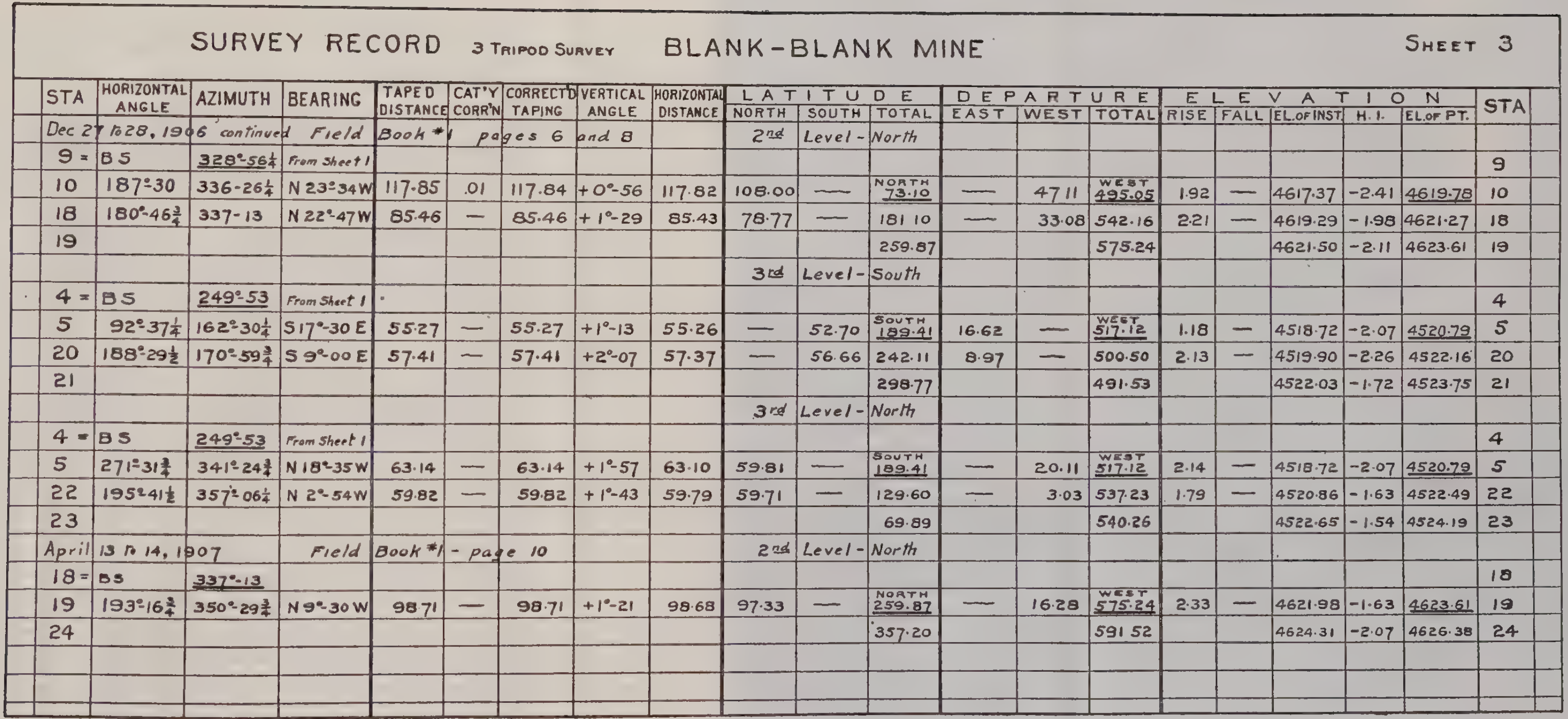
FIG. 48.—Survey record. Sheet 1.



SURVEY RECORD 3 TRIPOD SURVEY BLANK-BLANK MINE SHEET 2

STA	HORIZONTAL ANGLE	AZIMUTH	BEARING	TAPED DISTANCE	CAT'Y CORR'N	CORRECT'D TAPING	VERTICAL ANGLE	HORIZONTAL DISTANCE	LATITUDE			DEPARTURE			ELEVATION					STA
									NORTH	SOUTH	TOTAL	EAST	WEST	TOTAL	RISE	FALL	EL OF INST	H. I	EL OF PT.	
Aug 13 to 15, 1906 continued Field Book #1, pages 4 to 5									1st Level North											
2 =	B S	249°53	From Sheet 1																	2
3	269°-20	339°-13	N 20°-47 W	53.47	—	53.47	-0°-57	53.46	49.98	—	SOUTH 110.71	—	18.97	WEST 302 26	—	0.88	4711.50	-1.98	4713 48	3
11											60.73			321.23			4710.62	+4.07	4706 55	11
									1st Level South											
2 =	B S	249°-53	From Sheet 1																	2
3	94°-10½	164°-03½	S 15°-56 E	62.59	—	62.59	-0°-17	62.59	—	60.18	SOUTH 110.71	17.18	—	WEST 302 26	—	0 31	4711 50	-1.98	4713.48	3
12	183°-19¼	167°-22¾	S 12°-37 E	114.79	.01	114.78	+2°-03	114.71	—	111.94	170.89	25.06	—	285.08	4 11	—	4711 19	-2.09	4713 28	12
13	61°-47	49°-09¾	N 49°-10 E	97.49	—	97.49	+38°23	76.42	49.97	—	282.83	57.82	—	260 02	60.53	—	4715 30	+4.17	4711 13	13
14											232.86			202 20			4775 83	Tempurary		14
									1st Level South											
12 =	B S	167°22¾																		12
13	164°-23	151°-45¾	S 28°-14 E	103.09	—	103.09	+ 1°-47	103.04	—	90.78	SOUTH 282.83	48.74	—	WEST 260.02	3 21	—	4715.30	+4 17	4711.13	13
15											373 61			211.28			4718.51	Tempurary		15
Dec 27 to 28, 1906			Field Book #1, page 7						2nd Level South											
4 =	B S	165°-10¾	From Sheet 1																	4
6	184°-23	169°-33¾	S 10°-26 E	65.21	—	65.21	+0°-57	65.20	—	64.12	SOUTH 229 38	11.81	—	WEST 392 43	1.08	—	4614 15	-2.85	4617.00	6
16	169°-38½	159°-12¼	S 20°-48 E	63.87	—	63.87	+ 1°-29	63.85	—	59.68	293.50	22 66	—	380.62	1.65	—	4615 23	-2.14	4617.37	16
17											353.18			357.96			4616 88	-2 05	4618 93	17

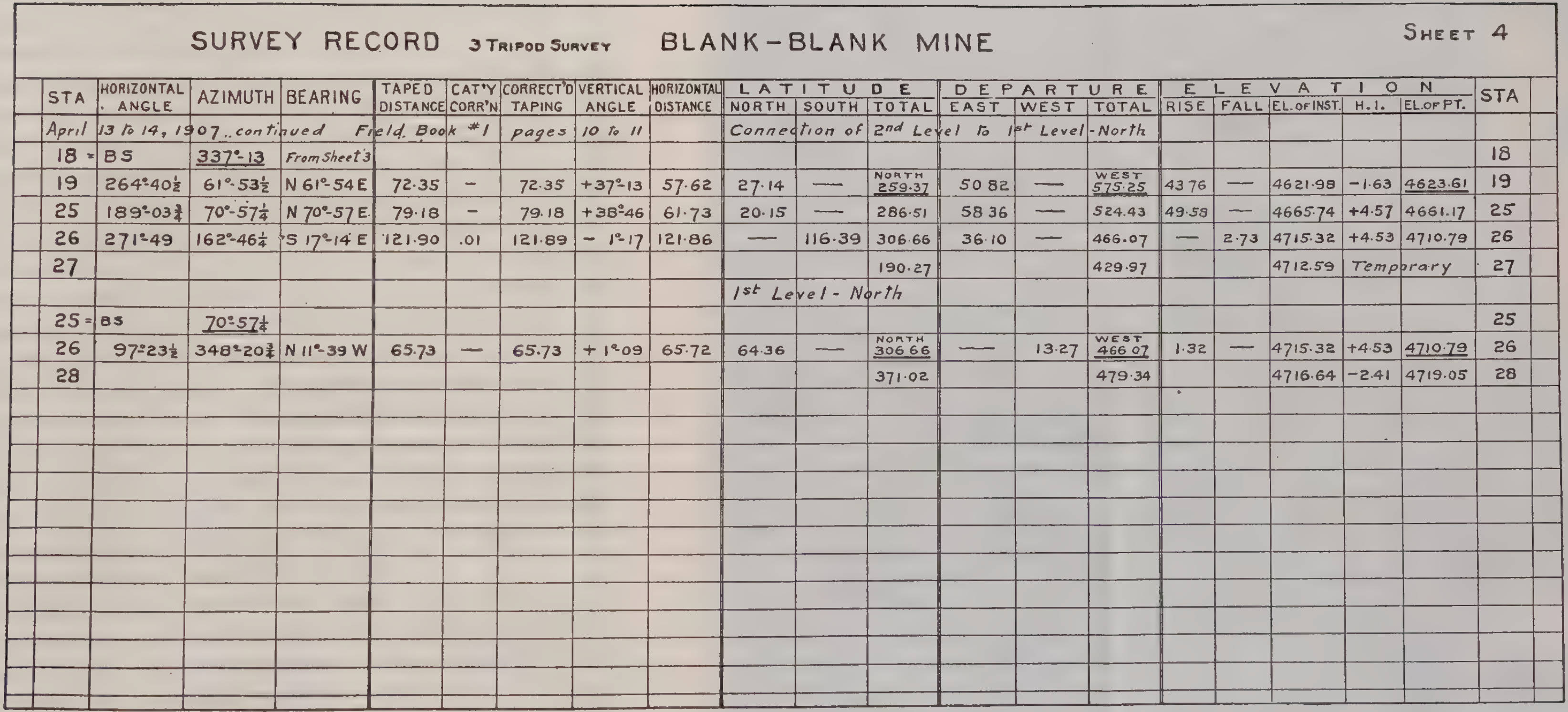
Fig. 49.—Survey record. Sheet 2.



SURVEY RECORD 3 TRIPOD SURVEY BLANK-BLANK MINE SHEET 3

STA	HORIZONTAL ANGLE	AZIMUTH	BEARING	TAPED DISTANCE	CAT'Y CORR'N	CORRECT'D TAPING	VERTICAL ANGLE	HORIZONTAL DISTANCE	LATITUDE			DEPARTURE			ELEVATION					STA
									NORTH	SOUTH	TOTAL	EAST	WEST	TOTAL	RISE	FALL	EL. OF INST.	H. I.	EL. OF PT.	
Dec 27 to 28, 1906 continued			Field	Book #1	pages 6		and 8		2nd	Level -	North									
9 =	B S	328°-56¼	From Sheet 1																	9
10	187°-30	336-26¼	N 23°-34 W	117.85	.01	117.84	+0°-56	117.82	108.00	—	NORTH 73.10	—	47 11	WEST 495.05	1.92	—	4617.37	-2.41	4619.78	10
18	180°-46¾	337-13	N 22°-47 W	85.46	—	85.46	+ 1°-29	85.43	78.77	—	181 10	—	33.08	542.16	2.21	—	4619.29	- 1.98	4621.27	18
19											259.87			575.24			4621.50	-2.11	4623.61	19
									3rd	Level -	South									
4 =	B S	249°-53	From Sheet 1																	4
5	92°-37¼	162°-30¼	S 17°-30 E	55.27	—	55.27	+1°-13	55.26	—	52.70	SOUTH 189.41	16.62	—	WEST 517.12	1.18	—	4518.72	-2.07	4520.79	5
20	188°-29½	170°-59¾	S 9°-00 E	57.41	—	57.41	+2°-07	57.37	—	56.66	242.11	8.97	—	500.50	2.13	—	4519.90	-2.26	4522.16	20
21											298.77			491.53			4522.03	-1.72	4523.75	21
									3rd	Level -	North									
4 =	B S	249°-53	From Sheet 1																	4
5	271°-31¾	341°-24¾	N 18°-35 W	63.14	—	63.14	+ 1°-57	63.10	59.81	—	SOUTH 189.41	—	20.11	WEST 517.12	2.14	—	4518.72	-2.07	4520.79	5
22	195°-41½	357°-06¼	N 2°-54 W	59.82	—	59.82	+ 1°-43	59.79	59.71	—	129.60	—	3.03	537.23	1.79	—	4520.86	- 1.63	4522.49	22
23											69.89			540.26			4522.65	- 1.54	4524.19	23
April	13 to 14, 1907		Field	Book #1	- page 10				2nd	Level -	North									
18 =	B S	337°-13																		18
19	193°-16¾	350°-29¾	N 9°-30 W	98.71	—	98.71	+1°-21	98.68	97.33	—	NORTH 259.87	—	16.28	WEST 575.24	2.33	—	4621.98	-1.63	4623.61	19
24											357.20			591 52			4624.31	-2.07	4626.38	24

Fig. 50.—Survey record. Sheet 3.



SURVEY RECORD 3 TRIPOD SURVEY BLANK-BLANK MINE SHEET 4

STA	HORIZONTAL ANGLE	AZIMUTH	BEARING	TAPED DISTANCE	CAT'Y CORR'N	CORRECT'D TAPING	VERTICAL ANGLE	HORIZONTAL DISTANCE	LATITUDE			DEPARTURE			ELEVATION					STA
									NORTH	SOUTH	TOTAL	EAST	WEST	TOTAL	RISE	FALL	EL. OF INST.	H. I.	EL. OF PT.	
April 13 to 14, 1907 .. continued Field Book #1 pages 10 to 11									Connection of 2nd Level to 1st Level - North											
18 =	BS	337°-13	From Sheet 3																	18
19	264°-40½	61°-53½	N 61°-54 E	72.35	–	72.35	+37°-13	57.62	27.14	—	NORTH 259.37	50 82	—	WEST 575.25	43 76	—	4621.98	−1.63	4623.61	19
25	189°-03¾	70°-57¼	N 70°-57 E.	79.18	–	79.18	+38°-46	61.73	20.15	—	286.51	58 36	—	524.43	49.58	—	4665.74	+4.57	4661.17	25
26	271°-49	162°-46¼	S 17°-14 E	121.90	.01	121.89	− 1°-17	121.86	—	116.39	306.66	36.10	—	466.07	—	2.73	4715.32	+4.53	4710.79	26
27											190.27			429.97			4712.59	Temporary		27
									1st Level - North											
25 =	BS	70°-57¼																		25
26	97°-23½	348°-20¾	N 11°-39 W	65.73	—	65.73	+ 1°-09	65.72	64.36	—	NORTH 306 66	—	13.27	WEST 466 07	1.32	—	4715.32	+4.53	4710.79	26
28											371.02			479.34			4716.64	−2.41	4719.05	28

FIG. 51.—Survey record. Sheet 4.

CHAPTER VI

MAPS AND PROJECTIONS

The map is the principal record of most mine surveys, and is a miniature of the mine on paper, where all of its parts can be conveniently studied. The importance of the work and the nature of the problems to be solved determine the character of the maps required, the degree of accuracy of the survey and the amount of detail that it is necessary to take in the field. Thus, if the map of a mine is to be drawn to a scale of 100 ft. to the inch, a distance of 2 or 3 ft. in the position of the walls will be imperceptible on the map, being less than the width of a heavy line, hence it will be useless to measure distances to the walls closer than 2 ft. or to take notice of variations in the form that will be too small to show on the map. On the other hand, if the plot is to be on a large scale, say 10 ft. to the inch, and the map is to be used for the location of a mechanical haulage system, the measurements must be taken with more care. In narrow places, or where curves, turnouts, or other special construction may occur, it will be necessary to locate the walls very carefully, and it may be necessary to locate the timbers, in order to determine which can be cleared by the trains and which will have to be moved. On maps of this scale, a distance of $\frac{1}{2}$ ft. is easily discernible.

Scale.—Where a mine is not too large to be drawn on a sheet of reasonable size, a scale of 50 ft. to the inch is a good one for the working map. This would allow a strip of country nearly 1500 ft. in width to be plotted on paper 30 in. wide. This scale allows the plotting to be done to the nearest foot, and is large enough to show details very clearly.

Where a mine is large or there are several adjacent workings that are wanted on the same sheet, it may be necessary to plot to a scale of 100 ft. to the inch. This is the scale used in the anthracite coal fields of Pennsylvania, where the mines cover large areas; this scale is fixed by the laws of the State for the maps prepared by the mining companies for the use of the Mine Inspectors.

Maps of districts showing the relations between various workings are often made to a small scale of 200 or more feet to the inch. On these maps, the minute details are not required and they are usually made by combining several of the working maps and reducing them to the smaller scale by means of a pantograph. These maps being intended for general information are only brought up to date at long intervals, say once a year, while the working maps are often posted every month.

Point of Origin and Base Line.—Where only a single mine is being mapped by itself, it may be drawn to any scale, and the calculations based on any point of origin and on any base-line. It is preferable, however, to use a uniform scale, say 50 ft. to the inch, for the working drawings, and to make the base-line lie in a north and south direction. If it is not convenient to determine the true meridian, the base-line may be fixed arbitrarily, but such a line should be noted as being an approximate meridian.

Where there is a group of mines, all the surveys should be connected to a common point of origin, and the azimuths all calculated from the same base-line, which should be preferably the true meridian. If the mines are far apart and it is not feasible to connect them, before the individual surveys are made, then each should be oriented by a true meridian determined astronomically, and its ordinates connected to an initial monument that later can be tied in by a general traverse connecting all the members of the group.

The elevations can be figured from an assumed datum, until a definite one can be brought in from some reliable bench mark. The datum should be taken low enough to give positive elevations to all underground points. The elevation of some point of the survey may be obtained approximately by taking the average of a number of barometric readings on clear days, at that point.

Paper.—The character of the paper used for the working map is of great importance. The value of the work put on the sheet is far greater than the cost of the best paper obtainable. The paper must last many years and will be subjected to a great deal of handling, hence it must be heavy, of the best grade, and backed with cloth. The surface should be smooth so that the drawing can be made accurately and so that colors can be applied uniformly with a brush. It should be firm enough to stand erasures and permit redrawing on the rubbed surface without causing the ink to spread. Whatman's "not hot pressed" paper is a good paper, but it comes in sheets, the largest being 31 by 53 in., and hence it can only be used for small maps. The heavy drawing papers of other makes, but with a similar surface and body, are made from 3 to 6 ft. wide and are carried in stock in rolls of 10 or more yards, so large pieces can be easily obtained. These heavy papers cost about 35 cents a square yard when unmounted and about 85 cents a square yard when mounted on muslin, in 10-yard rolls. Special sheets of any size can be made up by dealers who bevel the edges of the narrower sheets, and then lap and paste them together on a cloth backing. One firm reports having made a sheet 15 by 30 ft. for a land map by this method.

The paper should be white so as to take colors properly, and so that it will not be excessively dark after it has collected dirt and yellowed with age. The edge should be bound with a tape to insure it against tearing.

Coordinate System.—The first step in plotting a map by coordinates is to lay out the horizontal coordinate lines on the sheet. These are drawn parallel to and at right angles with the meridian through the point of origin. Great care should be used to have them properly spaced and accurately drawn, as all subsequent measurements are made from them. If the paper changes, by stretching or shrinking, so that the spaces between the coordinate lines cease to agree with the original scale used in laying out the coordinate system, no error is introduced, as the spaces between these coordinate lines are the scale for all long distances independent of the original scale. The loose scale is only used for plotting between the coordinate lines and so the shrinkage errors are confined to short distances and are imperceptible.

The coordinate lines should be laid out with a beam compass, by constructing a main rectangle by geometric methods, and then subdividing it into squares by a system of parallel lines. T-squares and triangles are not accurate enough for this work. The details of the operation are as follows: 1. Draw a line *A-B*, Fig. 52, lengthwise of the sheet with a straight-edge; the line should be in about the center of the sheet, and parallel to the sides; a steel straight-edge should be used for the best results. 2. From a point near the middle, as *C*, strike two arcs with the same radius giving *D* and *E*. 3. From *D* and *E* as centers with as long a radius as possible, strike arcs whose intersections give points *F* and *G*. 4. Draw a line through *F* and *G*; it should pass through *C* and it will be perpendicular to *A-B*; the arcs and centers should be so chosen as to give good intersections. 5. From *F* and *G*, with a radius *C-D*, strike arcs to the right and left. 6. From *D* and *E*, with a radius *C-F* = *C-G*, strike arcs above and below, intersecting the arcs from *F* and *G* and giving the corners of the rectangle, *H*, *K*, *L*, and *M*. 7. Join these corners, giving

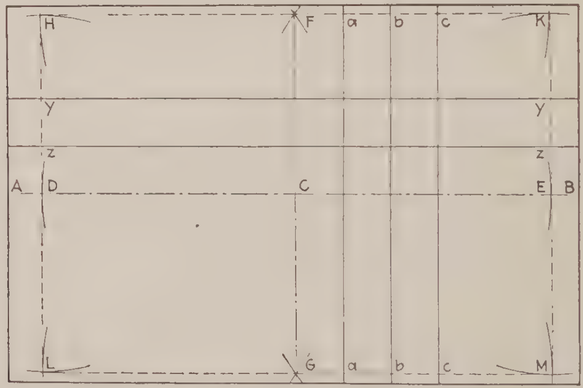


FIG. 52.—Construction of the main rectangle for coordinate plotting.

the sides of the main rectangle which may be extended to the edge of the paper; the accuracy is increased by making the construction rectangle nearly as large as the sheet, which can be done by using a long beam on the compass, then the errors of drafting are not multiplied by extending the lines beyond the construction points; the accuracy of the drafting may be checked by measuring the diagonals *K-L* and *H-M*, which should be equal. 8. If the point *C* is to be the point of origin of the plot, and the line *F-G* the meridian, then set the dividers at the distance that is desired between the coordinate lines, say 2 in., and step off these distances from the points *F* and *G* to the east and west along the top and bottom lines of the rectangle, giving the points *a*, *b*, *c*, etc., and from the points *D* and *E* to the north and south along the two end lines giving the points *z*, *y*, etc. 9. Draw a series of horizontal and vertical lines through the corresponding points on the sides of the main rectangle, thereby dividing the sheet into squares. Number the lines to indicate their distance from the origin as in Fig. 58.

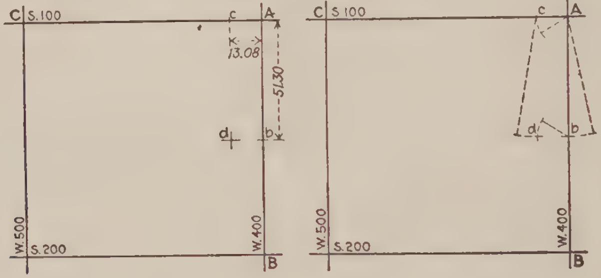
If the point of origin is not wanted at *C*, its position should be located and a pair of base-lines drawn through it parallel to *D-E* and *F-G*, and then the other coordinate lines can be laid out from the new base.

The coordinate lines are often drawn in with green ink, which distinguishes them from all other lines. The lines should be fine and solid.

The distances between the coordinate lines depend somewhat on the surveyor's ideas and somewhat on the scale of the map. If they are closer together than 2 in. they are too prominent on the map, and confuse the details instead of forming an unobtrusive skeleton on which the map is built. At 2 in. apart, the spaces correspond to distances of 100 ft. on the ground for a map at 50 ft. to an inch, and to 200 ft. for a map at 100 ft. to an inch. On maps of 200 ft. to an inch, lines 2½ in. apart represent 500 ft. on the ground. This distance of about 2 in. between the lines is a convenient one for plotting, and is generally used for working maps. Sometimes on general maps, the coordinate lines are drawn 4 or 5 in. apart, as these lines are not referred to very often, and too many of them might confuse the fine details.

Plotting Stations.—The survey stations are plotted by their total coördinates measured from the nearest coordinate lines laid out on the sheet, thus, Sta. 4 of the survey of the Blank-Blank Mine is at a point South 151.30 and West 413.08, and it is laid out 51.30 ft. south of the South 100 line and 13.08 west of the West 400 line.

In laying out a point either of two methods may be used: 1. By parallel lines, Fig. 53-*A*, where the latitude is laid off 51.30 ft. south from the corner *A* at *b*, on the line *A*-*B*, and the departure is laid off 13.08 ft. west from *A* at *c* on the line *A*-*C*; then with two triangles or a parallel ruler, lines are drawn through these points parallel to the coordinate lines and intersecting at *d*, which is the location of Sta. 4. 2. By intersecting arcs, Fig. 53-*B*, two dividers are used, preferably of different patterns and one having a pencil point; set one for the distance of the latitude = 51.30, and the other for the departure = 13.08; mark or prick off the distance *A*-*c* equal to the departure with the left hand and strike arcs with the pencil compass, using the right hand, from *A* and *c* to the south equal to the latitude; this gives point *b* and an arc on which *d* will fall; then from *b* prick off the distance *b*-*d* equal



A *B*

FIG. 53.—Plotting stations. *A*, by means of parallel lines; *B*, by means of intersecting arcs.

to the departure thus fixing the point *d* which is the location of Sta. 4. The latter method is the better of the two as the distances can be more accurately transferred by the dividers or the compass than by measurements with a scale, especially if a diagonal scale is used, where the graduations do not come to the edge. The trick of using both hands, the one for departures and the other for latitudes, is easily learned, is quick and prevents confusing the two quantities.

If the point is nearer the next line, it is more convenient to measure backward by setting the 100-foot mark of the scale on that line and marking the distance backward or by taking off the difference between the distance and the 100-foot mark with the dividers, thus making the scale perform the subtraction.

The station is marked by a prick mark and surrounded by a red ink circle about $\frac{1}{12}$ in. in diameter drawn with a bow compass. The number of the station is written near in small red figures and permanent stations are connected by fine red lines which represent the lines of the traverse. The traverse lines are not drawn inside the small circles thus leaving the prick mark of the station point always clear and plain. Temporary stations are drawn in and numbered for plotting. They may be inked but no traverse line is drawn to any other station, thus showing their temporary character. It is better, however, to leave them in pencil as nothing will be lost after the plot has been made if their positions are not preserved.

After each station is plotted, the distance to it from the last station should be measured with the scale and the bearing or azimuth of the line should be measured with a protractor; if these do not agree with the horizontal distance and the direction of the line given on the survey sheet, the reason for the discrepancy should be investigated. These tests not only verify the plotting but afford additional checks on the calculations of the traverse.

The elevations of the station points are noted near them on the map. These being part of the map proper are written in black ink. When a point is in the roof it is preceded by the letter *R*, but when in the floor no prefix is given to it.

See Fig. 58, at end of this chapter, for applications of the various methods of plotting the traverse.

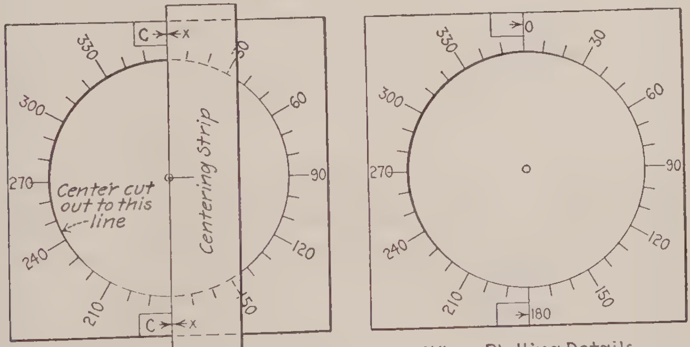
Plotting Details.—The details from the right-hand pages of the note book are now plotted on the skeleton formed by the traverse lines, making a complete map as in Fig. 58.

The offsets are laid off at the proper distances along the traverse lines. If the lines are inclined, the taped distances will be longer than the horizontal distances to be plotted on the map, hence the taped distances must all be reduced proportionately, to give the horizontal distance from the rear station to each offset.

In plotting radiating sights from the transit points, a protractor of large diameter should be used, so that angles of 10 or 15 minutes can be laid off. It should also be a full circle so that all the shots from any station can be plotted at one setting of the protractor. The work of plotting is facilitated by using a protractor with its center cut away; it is laid in place over a station, is oriented and weighted, and then a scale is laid with its zero on the station, its edge is brought to the proper angle on the protractor and the required distance is marked off. This not only saves time in plotting but saves the paper, since only the final marks are put on the map and the erasing of numerous points is avoided. It is convenient to stand a needle, using the finest size obtainable, at the station point, then the zero of the scale can be quickly set on the point. As fast as a point on the wall is located it can be connected with the previous one, and the map is completed as the plotting progresses.

The protractors printed on Bristol board are well suited for this work. They come in full circles; one size 8 in. in diameter is graduated to $\frac{1}{2}$ degrees and another size 13 or 14 in. in diameter is graduated to $\frac{1}{4}$ degrees; they cost 20 and 40 cents respectively. They are printed on solid rectangular cards and the degrees are not numbered; the draftsman can number the degrees and cut the cards to suit his needs. They are cheap hence there may be several in the office finished in different ways for different purposes.

When the central portion of a protractor is cut out for plotting, a bar must be left to mark the center for orienting the protractor. This is sometimes in the way and after plotting part of the notes the protractor must be turned through 180° to plot the balance. This stationary cross-bar may be avoided by using a movable strip to reach across the protractor and which has the center mark and the meridional line on it for orienting, see



When Orienting

When Plotting Details

FIG. 54.—Protractor for plotting details.

Fig. 54. The protractor and this centering strip are provided with matching lines and have cleats of cardboard glued to them so that they can be brought into the correct position with respect to each other. The centering strip and protractor are then matched together and oriented. The strip is removed and the protractor is anchored in position with weights. The centering piece is sometimes made as a tongue hinged to one side of the protractor so that it can be swung back but not entirely removed.

Paper scales are excellent for plotting; they are printed on cardboard about 18 in. long and are made to all the common scales. They can be numbered to suit the work on hand. They can be pivoted on the needle set at the station point and can then be swung in the direction of the line to be plotted without the necessity of setting the zero on the station point.

The outline of the workings, connecting the points along the walls determined by either offsets or radiating sights, should be connected by straight lines drawn free hand. This gives a positive outline to the walls without too much angularity and avoids the indefinite sketchy appearance that results when the lines are waved and the corners are rounded. The outline of the mine should be drawn in waterproof India ink. The exception to this use of black would be where there are several levels overlying one another, then each one would be drawn with a different color to distinguish it from the others. The outline of the workings is sometimes further strengthened by painting a narrow border of light water color just inside of the boundary line. This tint is changed from year to year and so shows at a glance what part of the mine was worked during any year.

Various notes should be added to the map to record features of interest that cannot be shown on a plan. Elevations of the floor and of the roof should be noted at intervals and when these occur with sufficient frequency the floor and roof can be contoured and vertical sections drawn wherever wanted. The character and thickness of the ore in the walls should be noted at various points as a guide to future work; this is especially important along a face where work has ceased or is about to be abandoned. Any geological data such as change in the character of the walls, presence of dykes or cross fissures should be entered on the map; the importance of noting these things has already been pointed out in discussing the field methods, see page 66. The date of the survey should be noted so as to show when the last survey was made and to indicate the progress made in the mining between the surveys. All these notes, being part of the map, should be entered in the same color of ink as used for the outline of the mine.

The working map should show the surface topography and the improvements that are immediately over the mine so that their relations to the workings may be kept in mind.

When the workings of different mines or of different levels of the same mine are vertically over each other, the resulting map may be very complicated, but the plot of each horizon may be separated for individual study by making one tracing of the surface and another of each level.[1] These tracings should have orienting marks on them so that they can be laid over each other and brought into correct relation with each other. This arrangement allows any level to be studied by itself or in connection with the level above or below it. Where it is desired to have the mine map convenient for reference, it has been suggested that the plan of each level be mounted on a curtain roller, placed in an overhead frame in the proper order, so that the drawing of any level can be pulled down and studied and then be run up while another is inspected.

Vertical Projections.—In all cases the main working map on which the surveyor plots his field work is either a simple plan or a series of horizontal projections of the mine workings.

With deposits having only a slight inclination, the plan gives an accurate idea of the area of the workings and the elevations noted on the plan at intervals show the undulations of the floor. If occasional elevations are also given to points on the roof, the height of the workings is shown.

If the deposit is steeply inclined, the size of the workings in the direction of the dip is very much distorted on the plan, and does not show the true progress of the work in the stopes, as the amount of work done in an upward direction may be greater than that done in a horizontal direction; further the workings on one level may overlap those on another and the horizontal plot become very confused. In such cases other projections are needed. These may be either a vertical projection parallel to the strike of the vein, vertical sections parallel to the dip and taken at various points, or an inclined projection parallel to the plane of the vein. The latter is often spoken of as a "plan on the vein."

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[1] A set of mine maps treated in this way and printed on transparent paper is given in a paper by D. W. Brunton entitled, "Geological Mine-Maps and Sections," A. I. M. E., Vol. XXXVI, p. 508.

Where horizontal, vertical or inclined projections are likely to be called for, the field notes must be taken with this in view, and the data be recorded for figuring the elevations of numerous points on the floor and roof of the working places. The plan of the foot wall will be plotted first; this locates the points in a longitudinal direction; then points may be transferred to the longitudinal projection and be plotted in connection with the elevations of these points as calculated from the field notes.

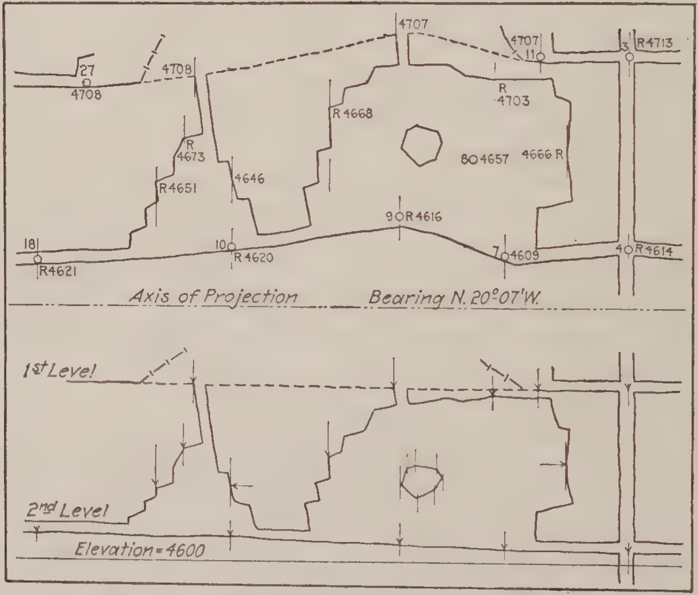

FIG. 55.—Making a vertical longitudinal projection.

A plan of the first stope on the north side of the Second Level, copied from Fig. 58, is shown in Fig. 55. If the vertical projection of this stope is wanted, a line X-X is drawn on the plan representing the intersection of the vertical plane of projection with the horizontal plane. This line may be drawn in any direction, but its position determines the position of the vertical plane.

It may be called the axis of projection; the projecting lines will be drawn normal to it. In this case, the vertical plane has been taken with a direction of N. 20°-07′ W., which is normal to the direction of the shaft, and agrees with the average strike of the vein. In making a plan on the vein, the plane of projection would be taken so as to conform as near as possible to the mean dip and strike of the vein.

The position of points on the walls are determined in a direction parallel to the strike by the plan and so may be projected onto the vertical projection as shown in the figure. The vertical position of the points will be determined by the elevation of these points as given on the plan, and will be laid off from a datum line on the vertical projection. The points whose vertical and horizontal positions are known are indicated in the figure by an arrow point in the vertical projection. After all the known points have been plotted, other points are located longitudinally by projecting from the plan, and their vertical position is determined by interpolating between the known points, as is shown for the pillar in the first stope from the slope. Where the elevation is given for the roof, the elevation for the floor may be obtained by subtracting the average vertical thickness of the vein. If the deposit is very irregular, the distance between the roof and floor should be measured for use in making the vertical projection. The vertical projection is seldom as accurate as the plan and is most useful as a picture to illustrate what is being done in the mine.

When the vein dips between 30° and 60°, the vertical and horizontal projections are very similar, and every change in the direction of the walls shows in both views, see Fig 55, where the dip is about 40°. For veins under 30° dip, there is not much use for a vertical projection, and for those over 60° the vertical projection is very important, and shows the progress of the work to the best advantage. The surveyor, however, always needs the horizontal plan to record his survey data, even if it is too complicated to be easily read. As far as possible the vertical projection should be a projection of the floor or foot wall, but some departures have to be made from this rule, for example, if the floor was all

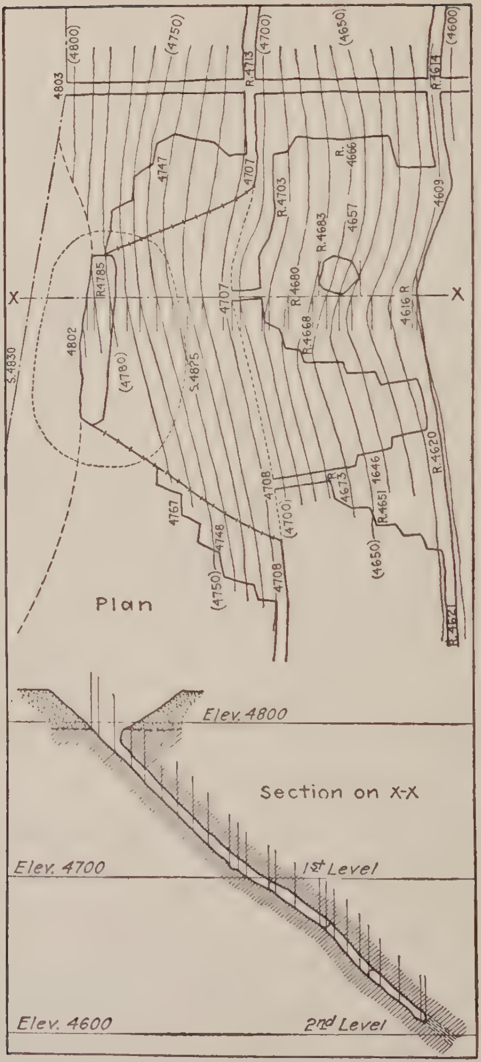

FIG. 56.—Making a vertical section.

that was shown of a drift, it would appear as a single horizontal line, hence the roof must also be drawn; again the roof line of the top of a stope must be shown or there would appear to be a thicker body of ore between the top of the stope and the next level than really existed. With thick deposits the vertical projections bear little resemblance to the plans and they must be constructed from surveys made especially to get data for them. The various projections of such a deposit are analogous to the plan, front and side views used in mechanical drawing to represent solid objects and each projection will contain information and dimensions that cannot be shown on the others.

Vertical Cross-sections.—These are often required to convey an idea of the inclination of the workings. If the plan contains frequent elevations of points in the floor and roof, these surfaces can be contoured, as in topographical surveying, and then a section can be drawn in any direction. For example, a vertical section on the dip is wanted along the line *X-X* in Fig. 56; this can be drawn by contouring the plan and then projecting the section, shown at the bottom.

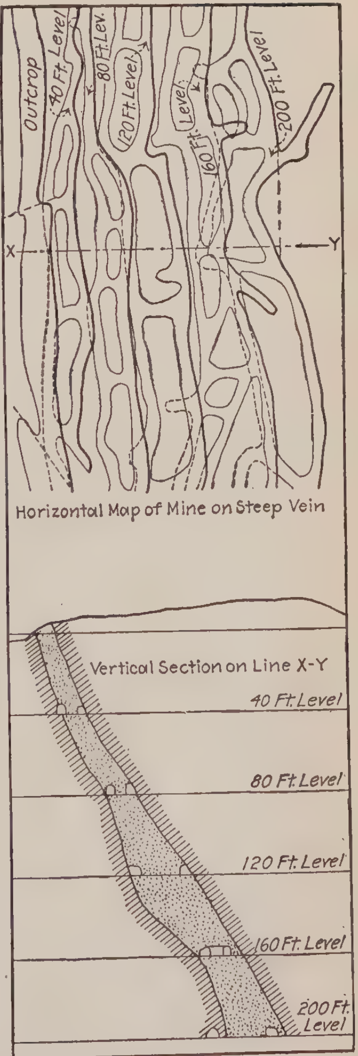

FIG. 57.—Making a vertical section on a steep vein.

In steeply inclined veins, vertical cross-sections are always required. The data for them can be obtained by running horizontal surveys through all the levels thus giving a series of horizontal plans or sections at the floor of the level. Knowing the relation of these horizontal sections to each other, the vertical sections can be worked out from them. Thus, Fig. 57 shows a composite plan of a mine with levels 40 ft. apart vertically and a vertical section developed parallel to the dip and on the line *X-X*.

If the levels are too far apart to give all the data needed, additional horizontal surveys can be run between levels through the timbering; but where the method of mining results in the filling of old workings or where the walls are allowed to cave, the surveys between levels must be made while the mining is in progress and while the stopes are open.

Mass deposits often require a series of vertical sections in order to show the conditions effecting the mining.

Care of Maps.—It is desirable that the originals of the working maps should be kept in a fireproof vault but where there is none, tracings should be made of the important maps and each time the maps are posted up, the tracings should be revised and blue prints of them should be stored in the residence of some of the officials which a fire would not be likely to destroy if the office should burn. Duplicate sheets of the survey record containing the results of the calculations should be similarly stored in a safe

Tracings should be made of all maps so that blue prints can be furnished the officials entitled to them; the original maps should not be allowed to go out of the office. Each tracing should have entries on it stating when the original was made, and the date of each revision. These would appear on the blue prints and would show whether the prints at hand contained the last revision or not.

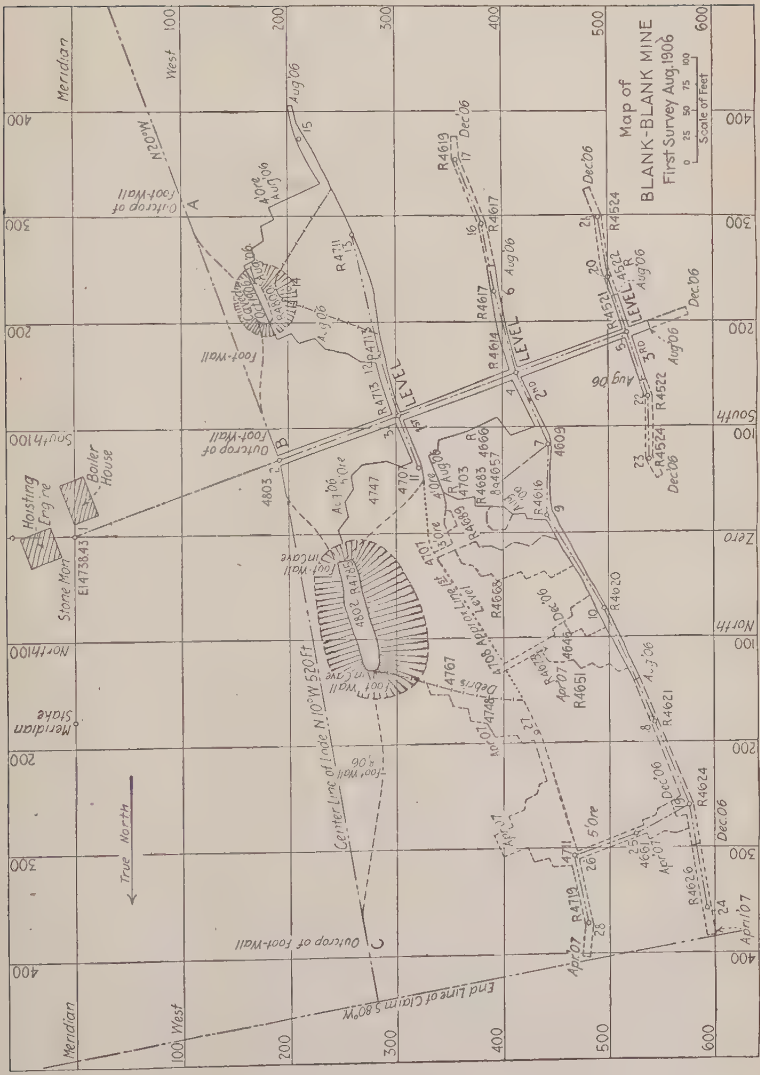

FIG. 58.—Plot of survey of the Blank-Blank Mine. Made from "Field Notes" at end of Chapter IV.

CHAPTER VII

SPECIAL MINE SURVEYS

COAL MINE SURVEYS

In General.—The principles in surveying the main lines and in collecting of the details in a coal mine are the same as for any other mine. The conditions, however, are different from metal mining. The area worked over in a month is large which necessitates a rapid system of surveying in order to cover the ground; the gangways are practically level which enables the survey to be run by the plummet method without paying attention to levels except on steep seams in passing from one level or gangway to another; the elevations are usually determined by leveling; vertical angles may have to be read in order to reduce tapings into steep rooms, to the horizontal, but no notes for figuring the vertical rise need be taken as the elevation is not needed. The problems of ventilation and of control of gases are very important in coal mining and everything relating to them must be noted on the map.

The main entries of a coal mine are usually driven perfectly straight and the grade maintained by taking up a little bottom or by filling and the head room is maintained by "brushing" down the roof. To facilitate the accurate location of these entries the survey lines should be kept exactly in their center or at a constant distance from one wall, so that the mine foreman can use the surveyor's points as a guide in extending the entries.

The gangways are usually driven nearly horizontally, but with enough grade to drain back toward their entrances; thus they nearly follow a contour of the floor of the seam. They are naturally crooked. In surveying them, a plug should be put in to mark the center of every room, so that the foreman will have the proper position for starting them. The foreman uses a pocket compass to give them the proper direction, and thus keeps them parallel. When a survey line is turned into a room, care should be taken that it is on the correct center line so the miners or the foreman can use the plugs in locating the direction of the room. The plugs at the mouths of the rooms should be set by the transit on the survey line between station points, so that they can be used to turn a side shot into any room desired.

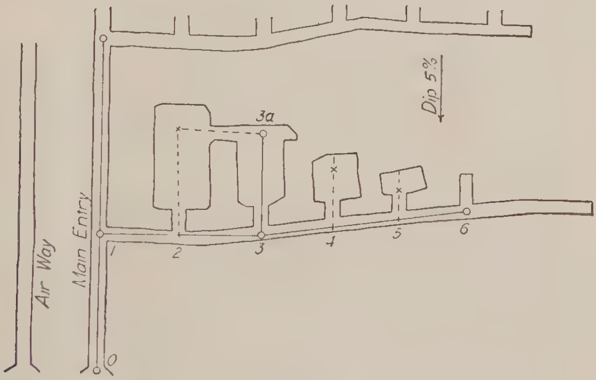

FIG. 59.—Survey of a coal mine.

Assume that it is desired to survey a gangway that has been turned off of a main entry, as in Fig. 59, and some rooms have been started. The transit is set up at the entrance to the gangway at Sta. 1, the angle is measured to the first station, marked 3, in the gangway, and an intermediate plug is set at the mouth of the second room and in line with the survey line between Sta. 1 and 3. Then the transit is set at Sta. 3, the angle to Sta. 6 is read, the intermediate plugs at the mouth of every room are set, a line is turned into the third room and Sta. 3*a* is set. Then setting up at Plugs 2, 4, and 5, lines are turned into the rooms and a plug is set on the center line of each.

When rooms are fairly regular, it is sometimes sufficient to turn the survey line into every third one and then to get details of the two intermediate rooms by taping, after they have been connected by "break throughs," thus the first room may be surveyed by offsets from a tape run in from Plug 2, a mark put at x opposite the heading and later tied in to Plug $3a$ as shown by the dotted lines.

On steep seams, where it is difficult to carry a line up the room on account of obstructions at its mouth, as loading chutes, etc., the face of the rooms can often be located by a survey line run through the headings connecting the room, as in Fig. 60.

In coal mines, the foremen use spads, made of horseshoe nails to guide the work of the miners, and the surveyor must be careful not to mistake them for his survey points. In order to have a distinct mark, it is well to use a loop of fine copper wire, held in a small hole in the roof with a wooden peg, see page 40, for the survey points.

A coal seam is often very regular and the scheme of work and the size and spacing of rooms can be laid out in advance with considerable precision. This tempts the surveyor to draw the map with a ruling pen and triangle and to make the working conform to the theoretical forms. The map then is not much more than a record of how far the work has progressed in any gangway, entry, or room, and it lacks the convincing character of a map that shows the irregularities as they are. A map that is prepared in advance to illustrate the method of working to be used, and to plan the ventilation is merely a project and can properly be drawn with geometrical outlines, but the map plotted from the survey should show things as they are, and even where wall lines are straight and conveniently ruled when drawn in pencil, it looks best to draw the ink line in with the free hand.

Anthracite Mines.—The surveys of the anthracite mines of the Susquehanna Coal Co. and the Lykens Valley Coal Co.[1] were made by a corps which consisted of a transitman, a stationman, a backsightman, a foresightman, a chainman, and a fireboss to attend to the safety of the party. The three tripod method was used but instead of lamps the wick tubes were replaced by a wire $\frac{1}{16}$ in. diameter by $\frac{3}{8}$ in. high, as giving a more accurate sight. The station points were all put in the roof and were of three kinds. First, a small conical hole was drilled in the roof and the bob suspended from an iron rod fitting into the hole. The point was transferred to a mark on the floor and the instrument set up over this. This kind of set-up had a greater liability of error than either of the following, and so was not often used. Second, a spad was driven into a plug in a hole in the roof, and the instrument set under a bob suspended from it. Third, the most convenient point was a hole $\frac{1}{16}$ in. diameter (drilled with a twist drill), into which a shoe peg was driven so as to hold a loop of fine, No. 26, copper wire. The wire was soft enough to pull down straight, the station was easily found when marked with a ring of white paint and it was never confused with a spad put in by the mine boss.

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[1] Abstract of "Anthracite Mine Surveying," by R. Van A. Norris, *S. of M. Quarterly*, July 1890, Vol. XI, p. 328.

The order of work on the survey was: the station marker, who was familiar with the mine and the methods of the survey party, went ahead and put in the station points being guided by the lights of the party behind and by that of the fireboss who went ahead; the foresightman carried the foresight tripod ahead, set it up under the point and then held his light while the transitman took the sight on the signal; the transitman after taking and recording the instrument sight, signaled, "Move up;" the backsightman moved up the rear tripod and signal, handed the tripod to the chainman, and held the zero of the 300-foot tape; the chainman went forward with the free tripod and the tape reel and delivered the tape to the foresightman; the transitman and the foresightman then measured the distance, the tape being marked by the foresightman with a brass clip; the foresightman then took the free tripod and the signal from his station and went ahead and set them up at the next station ahead; the backsightman held the zero of the tape and the chainman held the forward end while the transitman followed along the tape, made the sketch and took the side notes and on reaching the forward station recorded the distance; the backsightman carried the transit forward to the new station and returned and set up and illuminated the rear signal; the chainman wound up the tape, and the transitman took up his duties at the new station.

The angles were read by continuous azimuths, and the magnetic bearings were read as a check; the surveys usually closed within three minutes on a traverse of 15 or more stations. The elevations were carried along with the transit survey and later checked by a line of levels run through the gangways; they were usually within 0.10 ft., on a course of 50 stations. There was seldom a difference of over a foot between the elevations of side points as obtained by the transit and by those obtained with the level. Working in this way it was possible to attain great speed, from 40 to 50 stations being considered a fair night's work. In taking details, the transitman walked alongside of the tape, took his distances from it, and measured offsets to the walls at intervals and at every opening passed. The offset measurements were made with the eye by experienced men. In surveying the breasts, either a line was run through the headings, or where this was impractical, a line was run up every third breast noting all the headings and the two intermediate breasts were sketched in by measurements through the headings. The directions of side sights were noted on the left hand page of the note book together with the instrument notes and did not appear on the sketch. The gangway stations were plotted by latitudes and departures, and the stations in the workings filled in by plotting with a protractor. The details were then filled in from the sketch. Fig. 60 shows both the field sketch and the finished plot.

The survey corps of another anthracite mine[1] consisted of a transitman, a foresightman, a backsightman, and two side notemen. A fireboss was added to the party in gaseous mines; he decided where the party could go with safety, he kept in advance and occasionally assisted in the work.

The station points were conical holes drilled in the roof with a chisel pointed steel rod, and surrounded with white paint. When a station was to be occupied the cord of a plumb-bob was passed through a notch in the opposite end of the steel rod, used for

[1] Abstract of *Eng. and Min. Jour.*, Feb. 11, 1904.

drilling the hole and held in the hole in the roof so that it hung free.

The method of survey was the plummet method, and the angles were read as azimuths. The order of the work was: the transitman set up the instrument over the mark on the floor, made by the foresightman, then the backsightman held the bob cord in the station hole and the transitman shifted his instrument under the bob with the shifting head; the backsightman measured with a small tape, the height of the instrument, and the distance to the roof; he then called the height of instrument to the foresightman; the backsightman went to the rear station, held a plumb-bob from the station point and illuminated it for the transitman; the

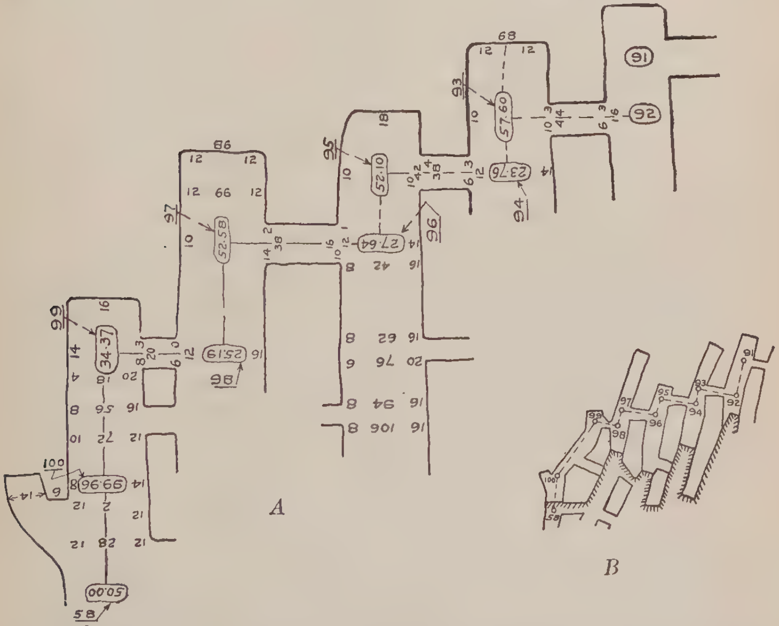

FIG. 60.—Sketch and plot of rooms in an anthracite mine. *A* is the sketch from the field book; *B* is the plot from the survey noted and sketch. The hatchings show previous surveys.

foresightman in the mean time had gone ahead, located a new station, drilled a hole, inserted the bob cord, lowered the bob to the floor, marked that spot with paint on a piece of slate, held the bob and illuminated it while the transitman took the foresight; he then held a mark on a graduated rod at the height of instrument given him by the backsightman, on which the transitman read the vertical angle; the second noteman assisted the foresightman; the first noteman had carried the tape reel at the forward station, and with the transitman measured the distance, which was usually from 75 to 100 ft.; the tape was then laid on the ground, the second noteman started at the zero end and called off measurements to the walls at intervals of not over 25 ft., using a light 6-foot stick to get the offsets; the first noteman recorded the offsets and made a section of the seam at the face; the transitman kept the instrument notes.

The survey stations were plotted by coordinates.

In surveying an anthracite mine with only one assistant,[1] plummet lamps were used as signals and the work was done in the following order: the stations were laid out and marked by spads in the roof; the transit was set at Sta. 2 by plumbing down from the roof to a point on a lead block laid on the floor over which the transit was set; the assistant hung a lamp at both the back and the forward stations and then held the light at the instrument for the final setting and while the readings were being taken; the angle was repeated and the compass read on both sights as a check; the transit was moved ahead and set at Sta. 3, while the assistant moved the rear lamp from Sta. 1 up to Sta. 2 and then took the forward lamp from Sta. 3 ahead to Sta. 4. After all the angles were read, the two went over the line, measured the distances from station to station and took notes of the workings, etc.

Bituminous Mines.—These are usually worked from` fairly level gangways and the area mined is large, see Fig. 61. These conditions permit the surveying to be divided between two parties, one doing the instrument work and the other taking the measurements and side notes,[1] each party consisting of a chief and two helpers. Where the amount of surveying is small, the same method could be carried out by having one party of three men do the two kinds of work alternately.

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[1] Eckley B. Coxe, *Trans. A. I. M. E.*, Feb. 1873, Vol. I, p. 378.

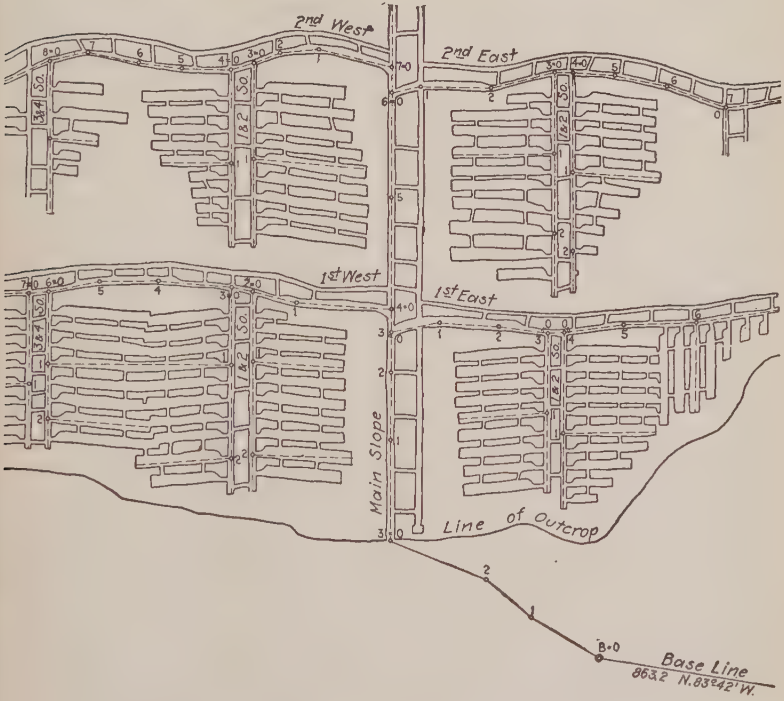

FIG. 61.—Map of a bitiminous mine, entered by a slope.

The first party sets the survey point, measures the distance parallel to the floor and takes the side notes. The organization of the work is as follows: the rear man is left at the last station, the chief goes as far as he can see him and chooses a convenient place for a station where he can also see the other man who has been sent on ahead; a mark is made where the point is to be set, and the station mark is painted about it; the party then moves ahead, the rear man stopping at the point marked and the chief locates a new point near where the head man stood while the latter goes on ahead. This method of locating between two points prevents running the line into a corner. This locating of points is continued until the end of the gangway is reached, then the party returns and puts the stations in the roof. Next, the two helpers take the tape and a plumb-bob apiece, hang the bobs from the stations, and stretch the tape about a foot from and parallel to the floor. The zero of the tape is held at the rear station. The chief then goes forward, notes the distance on the tape and the offsets at all the openings and occasionally to the walls; on arriving at the forward station the tape is stretched tight and the distance read by both the chief and the head man. This is continued to the end of the entry or gangway, then the party returns pacing the distance into working rooms and measuring those that have been finished or are likely to break through where not desired.

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[1] Abstract of "Mine Surveying and Mapping," by Charles E. Rowe, *Mining Reporter*, Sept. 29, 1904.

The second party does the instrument work. The chief of this party runs the transit; he sets it at the station, and when the set-up is complete except for the final leveling, the head man measures the height of the instrument and sets the target of his rod accordingly, and goes forward to the next station. The helpers illuminate the plumb lines at the two stations, and the chief reads and records the horizontal angle, and then takes the vertical angle to the forward target in order to get the inclination on which the taping was made. This party will also take side shots into rooms where necessary. If the rooms are fairly regular it will not be necessary to go into more than every third or fifth one. If there is no station at the entrance of a room, a light may be set on the floor opposite the entrance and lined in between stations with the transit, then a rough set-up over the light will be sufficiently good and a backsight may be taken on either the back or the forward station.

The details in coal mining surveys form a large part of the work and their collection must be simplified, but still maintain a practical degree of accuracy.[1] Accuracy depends on taking the offsets so that they will be typical or locate salient points rather than on measuring them with great exactness. On plots about $\frac{1}{50}$ in. is as small a distance as can be laid out, hence there is no need of locating the walls closer than the distance corresponding to $\frac{1}{50}$ in. on the map; where the scale is 100 ft. to the inch this means that measurements within 2 ft. are as accurate as can be plotted, and an experienced man can take short offsets with no greater error than this with his eye. If the maps are likely to be used for legal purposes, the distances should be measured as evidence of the care used in making them. The eyes should only be used for short distances in a mine, in any case, as the darkness is deceptive, and if the light is fainter than usual the walls will seem to be further away, and black space may appear like a wall 8 or 10 ft. away when really the wall cannot be seen at all. Eye measurements should be tested frequently with tape measurements to make sure that the judged distances are within the limit of error allowable.

In wide rooms, where the floor is too steep and smooth to walk on, the width can sometimes be measured by tying a chunk of coal to the tape and throwing it across to the other side, letting the tape run through the fingers and seizing it the instant that it stops; this will give the distance. If preferred, the distance can be found by throwing a string in the same way and then measuring the length of the string. Several trials are often needed to get the width of a large room.

VERTICAL SECTIONS

The cross-sections of excavations frequently have to be taken to see that they have been driven to the required size and in the correct position with respect to alignment and grade.

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[1] Abstract of "Mine Surveying," by O. C. Burkhart, *Col. Eng.*, March, 1894.

Sunflower Cross-sectioner.[1]—This was devised by Division Engineer Alfred Craven for taking the cross-sections on the New Croton Aqueduct in New York, in which sections were taken every 10 ft. throughout its length of 30 miles.

The instrument, see Fig. 62, consists of a wooden disc, 14 in. in diameter by $\frac{1}{4}$ in. thick, mounted on a tripod, and having a rest for a measuring pole pivoted to the disc in such a way that the upper side of the rest and consequently the lower side of the pole passes through the center of the instrument. The disc is graduated in degrees, the pole is marked with feet and tenths, and the rest has a zero mark at the center of the instrument and graduations to hundredths of a foot in order to subdivide the

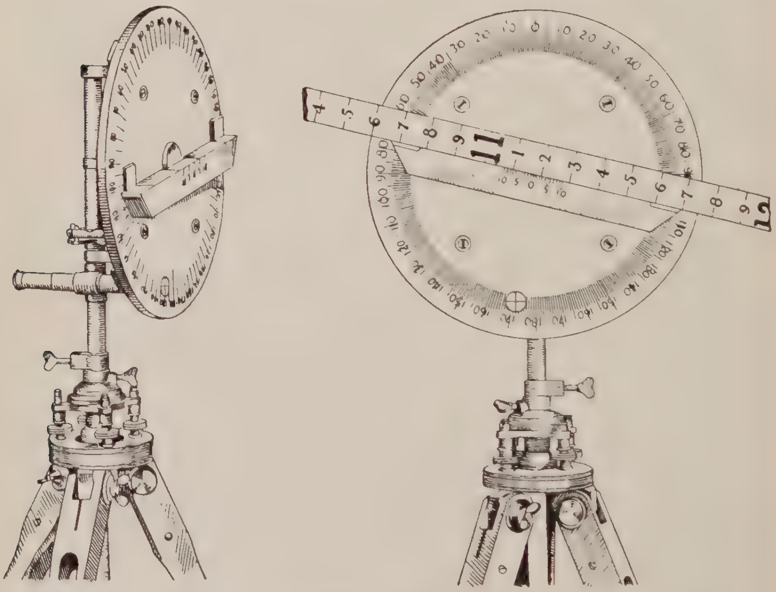

Fig. 62.—Sunflower cross-sectioner. Made by Heller & Brightly, Philadelphia, Pa.

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[1] *Proc. A. S. C. E.*, Vol. XXIII, p. 17, 1890.

tenths on the pole. The disc and attachments weigh 10 lb. and the tripod $10\frac{1}{4}$ lb. The poles are 1 in. wide and $1\frac{3}{8}$ in. high at one end and taper to $\frac{5}{8}$ in. in height at the outer or zero end. The poles are of any convenient length. Those used on the Aqueduct were 8 and 14 ft. long respectively and on later work on the New York Subway, a pole 20 ft. long was used. The zero ends of the poles are shod with brass to protect them from injury by the rock surfaces.

Station 1430 + 20. November 18, 1886.

East		West	
Angles in degrees	Distance in feet	Angles in degrees	Distance in feet
0	9.7	15	10.2
15	9.9	32	10.7
36	10.5	47	10.3
53	9.5	60	9.0
70	8.1	79	7.5
85	7.1	105	6.7
105	7.0	123	6.7
129	6.3	145	5.7
150	5.4	165	5.0
180	4.9	....	....

Axis 2.2 ft. below spring line of arch.

FIG. 63.—Field notes taken with a Sunflower cross-sectioner.

The instrument is set on the center line of the tunnel at a known distance from some station. The disc is plumbed by the level bubbles, raised to the desired elevation by sighting through the sight tube at a leveling rod held on a bench mark, and then set normal to the center line of the tunnel by pointing the sight tube to a line target.

The pole and its rest are then turned at various angles and the pole is extended to the tunnel wall, so as to make a series of radiating measurement. The direction is noted by the arc and the distance from the center to the wall is given by the graduation on the pole. Sufficient measurements are made so that on plotting them, a cross-section of the tunnel is obtained for that point. This can ordinarily be done in 6 to 10 minutes.

The notes are recorded as in Fig. 63 and these are plotted into the section shown in Fig. 64.

The plot of these notes is conveniently made with a protractor and scale. The area of the section can be measured with a planimeter, or if desired, it can be calculated, as it is equal to the sum of the areas of all the triangles, and the area of any triangle equals one-half the continued product of its two measured sides and the sine of the included angle at the center of the instrument. Thus the computation of the area of the first triangle on the east

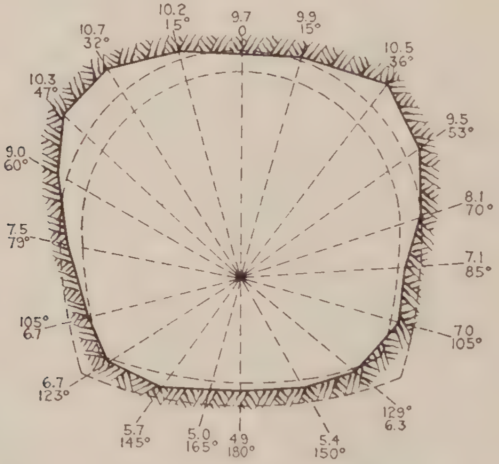

FIG. 64.—Plot of cross-section, from Sunflower notes, looking north.

Calculation of area of one triangle.

Station	Factors	Logarithms	Double area
1	9.7	0.98677	
	Sine 15°	9.41300	
	9.9	0.99564	
		1.39541	24.854 sq. ft. Area = 12.427 sq. ft.

side in the above section is shown below the figure. For convenience in making these calculations, two cards can be prepared, one having the logarithms of the numbers from 1 to 20 by tenths, and another having the sines of the angles from 1° to 60° by degrees. The number corresponding to the sum of the logarithms would be found from a standard table of logarithms of numbers.

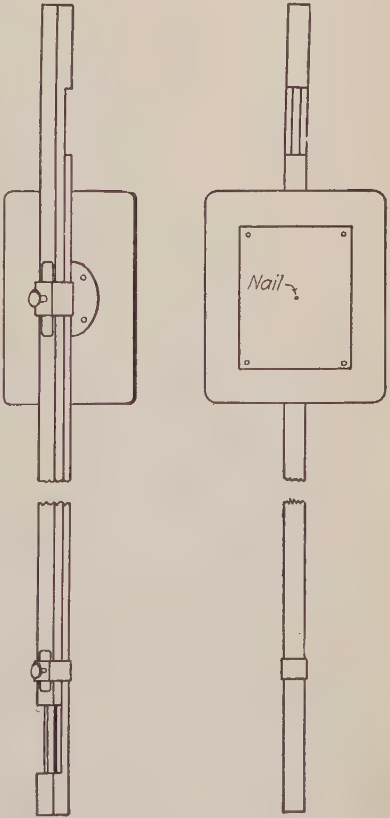

FIG. 65.—Young's cross-sectioner.

Young's Cross-sectioner.[1]—For small work, a simple instrument using the principle of the Sunflower was devised by E. E. Young. It consists of a board 12 by 14 by $\frac{3}{4}$ in. thick fastened to the target of a leveling rod by four screws. On this board, a block of paper is tacked, and through the paper at the center of the board a small wire finishing nail is driven, see Fig. 65. The leveling rod is set plumb on the center line of the tunnel, and is extended until its ends bear on both the floor and the roof of the tunnel and so hold the rod in position. The board is then set with its center at a known height above the grade line. In use, the vertical rod is held by one man, and a second man lays a light measuring stick across the center nail and reaching to the periphery of the tunnel. The direction of each position of the pole is recorded by drawing a line on the pad along the measuring stick and noting on this mark the distance to the wall, as shown on the stick. When the section is completed the sheet is torn from the pad and by plotting the length of the lines, a section of the tunnel is obtained on the paper, see Fig. 66. The device is similar to a plane table set vertically. A cross-section on sewer work ordinarily was taken in four minutes with the instrument.

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[1] *Eng. News*, June 20, 1901.

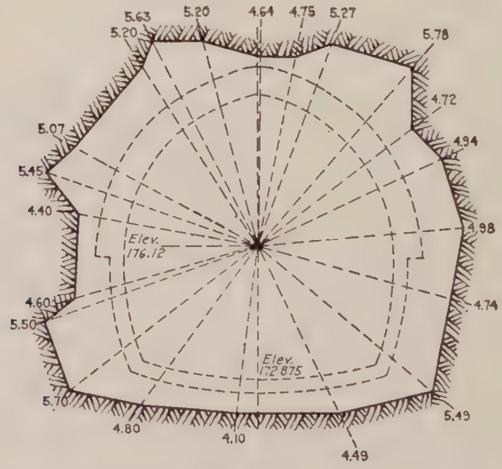

Fig. 66.—Completed plot of tunnel, taken with Young's cross-sectioner.

Railroad Clearance Cars.[1]—These are used to determine the clearance in tunnels and along structures near to railroad tracks. The car is fitted with a frame having an outline approximating that of a passenger car. This is fitted with fingers, 2 ft. long and 6 in. apart, so hinged that they will deflect on hitting an obstruction, and stay in that position. This car is slowly run through a tunnel and the position of the fingers show the size of the clear opening through the tunnel. It can also be used to get the cross-section at any one point by stopping the car at that point, and turning out the fingers until they strike the walls.

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[1] Two such cars were described in *Eng. News;* B. & O. R. R. car on June 13, 1907 and P. R. R. car on July 6, 1911.

VOLUMES

In General.—Underground work is often paid for by the cubic yard of material removed, and hence the volume of the excavation must be determined by actual measurement.

Where a vein of fairly uniform thickness is being worked, the volume can be obtained by multiplying the area stoped out by the thickness of the vein.

In tunnel work, the volume can be obtained by taking sections at known intervals and calculating the volume of the bore from these by the prismoidal or other formula.

In irregular chambers, the area of a series of parallel planes and the distance between them must be determined, and from these the volume can be calculated. In small chambers, the Sunflower instrument, or some modification of it, can be used. In large chambers, it is difficult to locate the position of the desired planes, and to get their area. The difficulties increase with the height of the chamber, because of the difficulties in reaching the concave roof. With scaffolds or ladders, a man can hold a light against the roof and the angles to the light can be measured with a transit and the distance can be taped, thus locating numerous points by radiating sights.

Where it is not feasible for a man to hold a light and tape against the roof, a light and the zero of the tape can sometimes be fastened to the end of a pole and be held against the roof. Then the sight can be taken on the light and the distance measured with the tape. This process is difficult with a very high roof as the pole is apt to slip when the tape is pulled, especially as the rodman becomes tired from holding the pole and his muscles relax unconsciously. The light is also a little distance from the roof.

The best method of measuring to a high roof is to use extensible rods and to measure the distance vertically. The rod might be held at intervals along a wire, or tape stretched along the floor to locate its position, and the height to the roof be determined on the principle of leveling; or the rod might be set at any convenient point in the section and its bottom end located both horizontally and vertically by a radiating sight from a transit, then by adding the length of the rod the elevation of the roof point would be given.

If the rod is used, care must be taken that loose flakes of rock on the roof are not detached which might injure some member of the party in their fall.

If it develops when the notes are plotted that the points chosen are not the best for calculating the volume, the roof, floor and walls of the chamber can be contoured and the sections plotted at more desirable points. Owing to the difficulty of choosing the best locations for the sections, it would seem better to take the measurement along sections that are approximately parallel, say 10 ft. apart, and calculate the volume from the area of these, assuming that they are representative sections. The error resulting from this assumption will probably not increase the total error due to poor location of the points in the sections and to inaccuracies in the measurements, which cannot be avoided in large chambers and in the darkness of a mine.

Abstracts.—The method used to collect the data, from which to calculate the areas of the sections will vary with the local conditions.

In a certain mine, it was necessary to get the volume of a drift that had a very small opening into the main workings. It was done by measuring a series of sections, located at points where the drift changed its size. To locate these sections, two cords were stretched from a post considerable outside of the neck of the drift and flared as much as possible without touching the walls. The points c and d were located on the cord so that the angles d-c-y and c-d-z were equal, see Fig. 67. Then by laying out the same distances along both cords, each successive cross line was parallel to the first one, and the vertical planes passing through these lines were parallel to each other. Marks on the cords were made by wrapping them with fine wire or by strings tied around them. The cords were stretched as taut as possible.

The areas of the sections were determined by right angle offsets, thus the section through the line *e-f* was obtained similarly to Fig. 68 where two plumb-bobs were dropped through the points *e* and *f*, a horizontal cord or rod was stretched across the drift in the plane of the two plumb-lines, and the necessary offsets were taken from these as base lines.

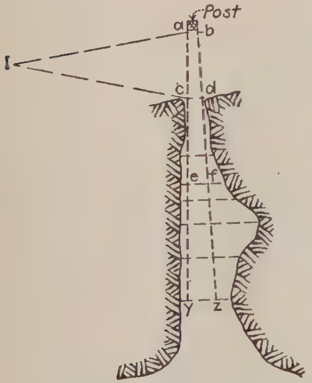

FIG. 67.—Volume of small drift.

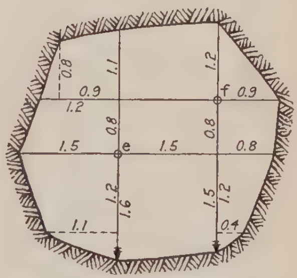

FIG. 68.—Cross-section of drift at points *e* and *f*.

The volume of each block was calculated by multiplying half the sum of the areas of its two bases by the horizontal distance between them.[1]

The drift was located with a transit set at a survey station, *I*, by taking radiating sights to two points on each cord, as *a*, *b*, *c*, and *d*. The distance *a-c* and *b-d* between the two points on the same cord should be measured as a check. It will simplify work if the cords are placed so that the line *c-d* is horizontal.

At another mine the volume of rock broken by each successive blast from the back of a stope was obtained by measuring the area of the vertical sections at intervals of 2 ft.[1]

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[1] "Method of Obtaining the Volume of Small Drifts," by C. S. Herzig, *Trans. A. I. M. E.*, August 1900, Vol. XXX, p. 778.

The excavation is shown in plan by Fig. 69. A cord was stretched from *B* opposite the reference point *A* to a point *X* on the wall. This cord was knotted every 2 ft. and the vertical sections were taken at each point. The successive sections taken at *B* after the blasts are shown by Fig. 70.

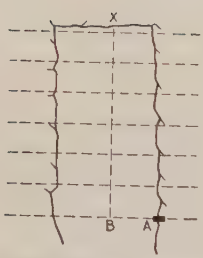

FIG. 69.—Plan of excavation.

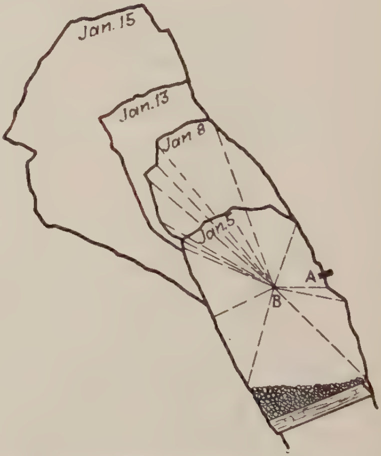

FIG. 70.—Successive sections through *B*.

In taking these sections, a tape was stretched from the point on the base cord to various points on the walls, the distance was measured by the tape, and the inclination of the tape was determined by a light pendulum clinometer attached to it. The area of the sections and the distance between them gave the data for calculating the volumes.

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[1] Discussion by Fred. T. Greene, *Trans. A. I. M. E.*, Vol. XXX, p. 1109.

CHAPTER VIII

SPECIAL PROBLEMS IN MINE SURVEYING

Problem of the Missing Side.—This problem is the determination of the length and direction of the missing or closing side of a polygon, the other sides of which have been measured by a traverse. It occurs in ordinary surveying but in mining work it reoccurs in so many forms that it is best to discuss it by itself and in detail, so that reference may be made to this discussion when the problem comes up later.

A simple case will illustrate the principle. The U. S. Mining Law requires that the initial corner of a mining claim be tied to some permanent monument, and the course and length of this tie line be given. It is often impossible to see the monument from the initial corner, or topographic conditions render it impossible to run the tie in a straight line, so a traverse is run, where convenient, from the corner to the monument, and then the course and length of the direct line is calculated and reported as the required line. A sketch of such a case is given in

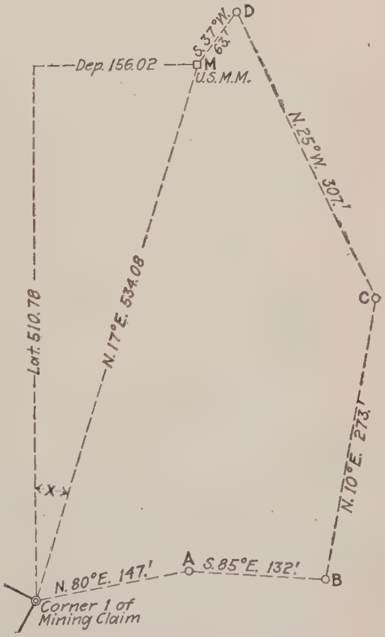

Fig. 71.—Problem of the missing side.

Fig. 71. Using Corner No. 1 as the origin, a traverse is calculated as in Fig. 72, giving the coordinates of the Monument. These two coordinates form the two legs of a right angled triangle of which the hypothenuse is the required line. Solving by the methods shown, gives the length and bearing of this line, hence the tie from Corner No. 1 to the Monument is described as N. 17° E., and 534.08 ft. long.

Sta.	Bearing	Hor. dist.	Latitude		Total	Departure		Total
			N.	S.		E.	W.	
Cor. 1.	N 80° E	147	25.52	....	00	144.77	....	00
A	S 85° E	132	....	11.51	N 25.52	131.50	....	E 144.77
B	N 10° E	273	268.85	....	14.01	47.40	....	276.27
C	N 25° W	307	278.23	....	282.86	....	129.74	323.67
D	S 37° W	63	....	50.31	561.09	....	37.91	193.93
Mon.	....	.....	....	....	510.78	....	....	156.02
		Proof	572.60	61.82		323.67	167.65	
			61.82			167.65		
			510.78			156.02		

Length of side, Cor. 1 to Mon. $= \sqrt{L^2+D^2} = \sqrt{(510.78)^2+(156.02)^2}$
$= 534.08$

Tan. $X = \frac{D}{L} = \frac{156.02}{510.78} = 0.3057$

Hence $X = 17°$ and bearing of line, Cor. 1 to Mon. = N. 17° E.

FIG. 72.—Calculations for problem of the missing side.

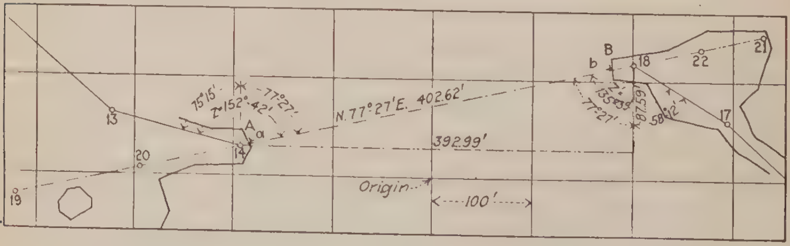

FIG. 73.—Survey for the connection from *A* to *B*.

In underground surveying this problem is used to determine the distance and direction between two points, between which it is desired to drive a connection. Thus, in Fig. 73, it is desired to drive a drift between *A* and *B* and it is necessary to know the distance that must be driven and the direction so that work can be carried on from both ends.

The mine has been surveyed and Sta. 14 and 18 have been set near *A* and *B* respectively. From the notes of this survey the total latitude, departure and elevation of the two stations and the azimuths of the last courses on each side have been determined and are given in Fig. 74. The differences between the total coordinates give the relations of one point to the other and by solving for the missing side, the course and length of the connecting line may be found. The connecting distance is horizontal and the difference between the elevations divided by this distance gives the slope, *i.e.*, the tangent of the angle of inclination of the line joining the two points.

Bearing 13 to 14 = S. 75°-15′ E.
Bearing 17 to 18 = N. 58°-12′ W.
Coordinates of 14 are: latitude = N. 29.28; departure = W. 192.09; elevation = 841.26.
Coordinates of 18 are: latitude = N. 116.87; departure = E. 200.90; elevation = 856.54.
Difference of latitude of 14 and 18 = 87.59 ft.
Difference of departure of 14 and 18 = 392.99 ft.
Difference of elevation of 14 and 18 = 15.28 ft.
Solving for the missing side gives:
    Distance 14 to 18 = 402.62 ft.
    Bearing 14 to 18 = N. 77°-17′ E.
    Inclination 14 to 18 = +2°-10′ or 3.8% up grade.
    Angle *Z* = 75°-15′ + 77°-27′ = 152°-42′.
    Angle *Z′* = 58°-12′ + 77°-27′ = 135°-39′.

Fig. 74.—Calculations for the connection, Fig. 73.

The course must now be laid out in the mine as a guide for the workmen. Setting the transit at Sta. 14 the telescope is reversed and set on the bearing of the course 13-14, then plunging, it is set on the bearing of the course 14-18, then the point *a* where the sight strikes the wall will be the center of the proposed drift. Or the plates may be set at zero, a backsight be taken on

13 and the angle Z may be turned off, thus making the telescope point in the direction of point 18. Having the telescope on the course of the proposed drift it should be plunged and permanent points 19 and 20 set on the line, so that the line of the drift can be quickly reestablished even if Sta. 14 should be destroyed by blasting. Having set 19, it will be well to prove its location by reading the angle between the courses 13-14 and 14-19 by the method used for the survey of the traverse, and if necessary, to correct its location so that it will be exactly on line. Sta. 20 can be lined in with the transit after 19 is fixed. The distances to both 19 and 20 should be measured, giving them the full authority of regular survey stations. Similarly, at the east end, Sta. 21 and 22 should be set. The distances from 14 and 18 to the walls subtracted from the total distance between 14 and 18 gives the net length of the drift to be driven.

In driving this drift the marks *a* and *b* on the walls set by the surveyor give the points at which work is started, but they are destroyed by the first blast. After that, the foreman keeps his direction by placing lights at any two of the permanent stations and ranging in a third light in the face of the drift, which marks the center for the drilling of the next round of holes. When the drift has advanced a little ways the surveyor should test the alignment with his instrument and when it has progressed far enough, a plug with a nail or a wire loop should be put in the roof on the center line, so that the foreman can hang a plumb-line from it for use in sighting. As the work advances, the surveyor keeps setting new plugs as close to the face as possible. For this work he sets the transit on some one of the permanent line points and takes the line from one of the others. When the work has progressed a considerable distance a regular survey station is set in the drift, on its center line, and is used for the subsequent alignment. The survey stations should be marked with the standard station spad so as to distinguish them from the foreman's center line marks. Similar work and marks will be needed to establish the alignment from the other end. The grade between the visits of the surveyor can be maintained by the foreman, if he is provided with a grade board about 12 ft. long, the two edges of which are not parallel but have a taper corresponding to the grade. By placing a carpenter's level on one edge he can test the floor or track to see that it has the proper slope to make the top side of the grade board level. The surveyor can test the grade by setting the telescope of the transit at the desired inclination and sighting into the drift. If the grade is right, the rod sights above the floor will be the same at all points as the height of the instrument. The grade can be checked with the level when the slope is small, but vertical angles must be used when the slope is steep.

In all problems of the missing side the traverse is not closed, hence it is necessary to watch the work very closely in order to prevent error; the magnetic bearings of all courses should be noted and all angles should be read by repetition. In very important work, where there is considerable at stake, the traverse should be checked by running an independent line between the terminal points. This, with the first traverse, will make a closed loop and errors can be detected. If there is only one route between the terminal points, the second traverse must be run along it but different station points should be used.

In addition to the calculations it is well to plot the traverse by coordinates to a large scale and test all the angles and distances by scaling. This affords a graphic check on all the office work after the field work has been checked.

This problem of connecting two points applies to the sinking of vertical and inclined shafts, as well as to the driving of tunnels or drifts to connect two points. It is always advisable to make a plot of the problem with a protractor and scale before beginning the work and the best method of solving the problem will often be indicated by such a plot. The plot will also give an approximate check on the calculations.

Problem of the Intersection of Lines.—There are many cases in mining where it is necessary to determine the point where two lines will intersect. These can be solved graphically where great accuracy is not essential and for approximate results it may be sufficient to scale the position off of the map. In any case, the drawing out of the problem to scale will be a valuable aid in pointing out the steps that are necessary to its solution.

One form of this problem is to determine the distance from the workings to the property line. Such a case is shown in Fig. 75 where it is desired to know the distance of the main drift from the boundary. The plane through the boundary line being vertical will be represented on the plan by a straight line and the

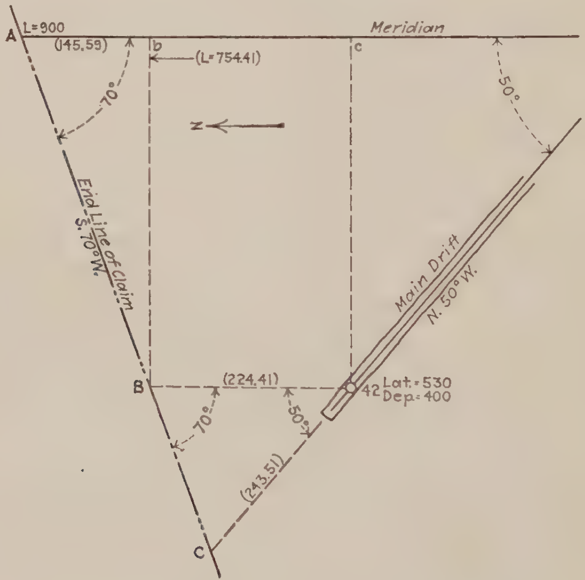

Fig. 75.—Distance of drift from boundary.

Known lines are drawn full; calculated and construction lines are drawn dotted. Calculated numbers are enclosed in brackets.

Let *B* be a point on the boundary with the same departure as Sta. 42. Then the *Latitude of B* = *Lat. A* − *A-b* = 900 − 400 *cot* 70° = 754.41 feet, and *Lat. B* − *Lat. Sta.* 42 = *distance from B* to *Sta.* 42 = 224.41 feet, which is one side of the triangle *B*-42-*C* whose angles are known, hence *Sin C* : *Sin B* : : 42-*B* : 42-*C*. Solving for 42-*C* gives 243.51 feet, which is the distance required.

question might take the form: How far beyond Sta. 42 will the center line of the main drift prolonged intersect the line representing the boundary? The solution is shown in the lower part of the figure. The distance of the end of the drift from 42 subtracted from the distance of 42 from C, gives the distance that the drift may be driven without crossing the boundary.[1]

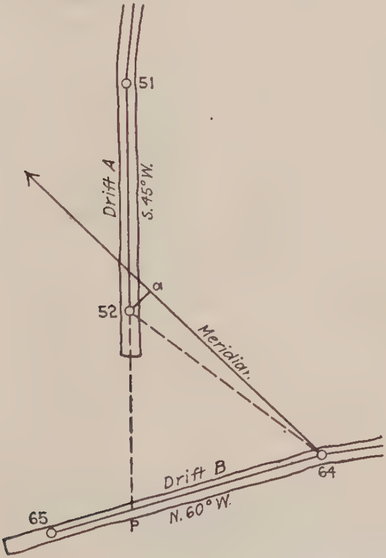

FIG. 76.—Intersection of drifts.

Another form of this problem occurs when two workings are close together and it is desired to drive from one to the other. Thus in Fig. 76, drift A is being driven toward drift B and it is desired to find the point P in drift B at which to begin work to meet drift *A*. The survey lines are taken as the center lines of their respective drifts. The latitude and departure of both 52 and 64 being known, a triangle 52-*a*-64 is constructed whose sides adjacent to the right angle equal the differences of the latitudes and of the departures of 52 and 64. This triangle can be solved for its distance 52-64, and for its angles, which gives data for the solution of the triangle 52-*P*-64.

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[1] Equations for the solution of any problem of this class are deduced in an article on, "Inaccessible distances in Surface and Underground Surveying" by H. S. Munroe and J. W. Davis, *S. of M. Quart.*, November, 1881, Vol. III, p. 25. The author believes that it is simpler to solve the few problems of this class that may occur by making a diagram and calculating the various right angle triangles by simple trigonometry as shown in the examples herewith.

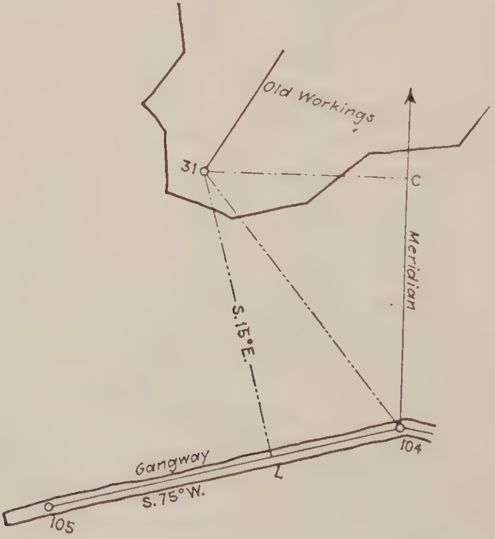

FIG. 77.—Location of a drift to a remote point.

Similarly in Fig. 77 it is required to drive the shortest connection from the gangway to the old workings, the entrance to which has been closed by a cave. The center line of the gangway is marked by the survey line 104 to 105 and survey station 31 in the old workings is taken as the objective point. The shortest line will be normal to the line 104-105, hence will have a bearing of S. 15° E., and will strike the center line of the gangway at some point as *L*. It is required to find the location of *L*. The method of solving this problem is identical with that used for Fig. 76, but the triangles are different in shape.

Distances to Veins.—The problem of finding the distance from the mouth of a shaft or tunnel to a vein is of frequent occurrence. When the proposed opening is in a direction normal

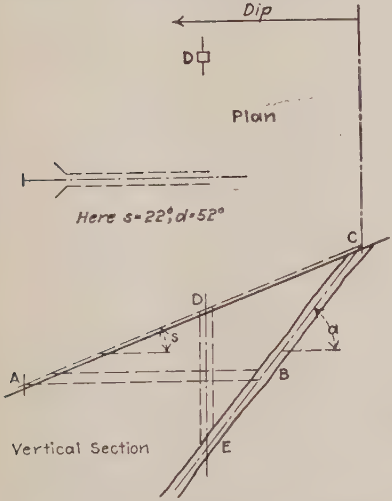

Fig. 78.—Distances to a vein, Case 1.

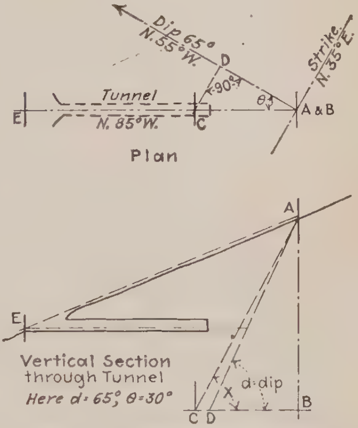

Fig. 79.—Distances to a vein, Case 2.

Calculations for Case 1.

In the triangle $A\text{-}B\text{-}C$, $\sin B : \sin C :: A\text{-}C : A\text{-}B$. The length of the tunnel $= A\text{-}B = A\text{-}C \dfrac{\sin C}{\sin B} = A\text{-}C \dfrac{\sin 30^\circ}{\sin 128^\circ}$

In the triangle $C\text{-}D\text{-}E$, $\sin E : \sin C :: D\text{-}C : D\text{-}E$, and the depth of the shaft $= D\text{-}E = D\text{-}C \dfrac{\sin C}{\sin E} = D\text{-}C \dfrac{\sin 30^\circ}{\sin 38^\circ}$

Calculations for Case 2.

Let X be the inclination of a line on the vein in the plane of the tunnel. Solving for X gives:

$\tan X = \dfrac{A\text{-}B}{C\text{-}B}$ but $C\text{-}B = \dfrac{B\text{-}D}{\cos\theta}$ and $B\text{-}D = \dfrac{A\text{-}B}{\tan d}$ then $C\text{-}B = \dfrac{A\text{-}B}{\cos\theta \tan d}$ and $\tan X = \cos\theta \tan d = \cos 30^\circ \tan 65^\circ = 0.8660 \times 2.1445 = 1.8571$. Hence, $X = 61^\circ\text{-}42'$ and having found X the length of the tunnel can be found as in Fig. 78.

to the strike[1] of the vein, it is a simple trigonometric problem, as shown in Fig. 78 and in the calculations below the figure. If the tunnel is not level, *i.e.*, has a small grade, as is common, or if the shaft is inclined, the problem is slightly different but still simple. The mere drafting of the conditions on a section normal to the strike will indicate the solution.

If the tunnel or incline does not lie in the plan of the dip, *i.e.*, is not in a vertical plane normal to the strike, the problem is more complexed but can be readily solved by figuring the inclination X of a line on the vein in the direction of the tunnel as is shown in Fig. 79.

In all vein problems, the strike and dip of the vein have to be assumed as uniform. As this is not the case, a mean dip and a mean strike are determined from a number of observations at a considerable distance apart, and these are used in the calculations; when the connection is driven the vein may not be found exactly at the calculated distance, but the error is not large with a vein of fairly uniform dip and strike. Drifts and shafts are represented in the calculations by a line to facilitate the solution of the problem.

Intersection of Planes.—The location of the outcrop of a vein is a problem in finding the intersection of the vein with the surface. The average plane of the vein can be assumed but the ground forms an unevenly twisted surface and the line of intersection between the vein and this surface can only be found by locating the point of intersection of the dip and the surface on each of a series of sections parallel to the dip, then transferring these to the plan or the ground and joining them. Thus in Fig. 80 a vein has been discovered at point A and the average of several observations gives the strike as N. 15° W., and the dip as 35° westerly. The plan shows the contours at 25-foot intervals. The probable position of the outcrop is determined at a series of points *b* and *c* and the outcrop line shown on the plan is obtained by joining these points. In the office the sections may be drawn and the probable point of the outcrop determined graphically as shown by the section in the figure, and then transferred to the plan.

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[1] Definitions: The dip is the inclination of a vein or stratum measured from the horizontal, and in a direction normal to the strike.

The strike is a horizontal line drawn on the plane of the vein. In flat country, its direction corresponds to the outcrop.

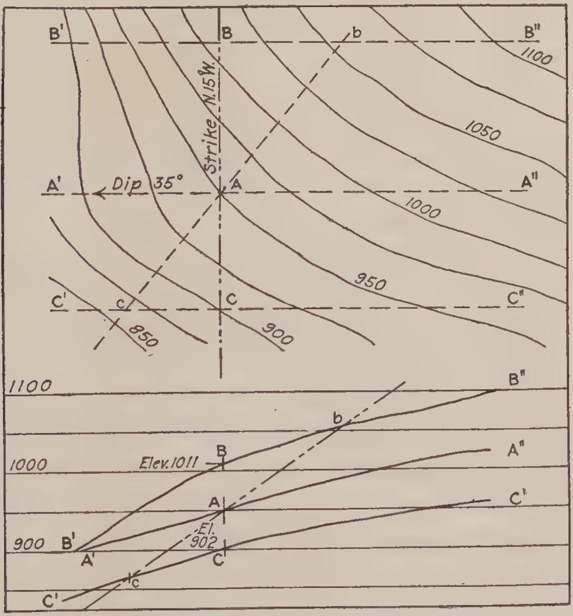

FIG. 80.—Determining the outcrop of a vein.

In the field the location of the outcrop is found by trial. Thus, at the north of *A*, the country in the direction of the strike is higher and hence the outcrop on section *B* will occur further up the hill than the line *A-B*. Let the elevation at *B* equal 1011 ft., this being 61 ft. higher than *A*, the outcrop at this elevation will be 61×cot 35° = 61×1.4281 = 87 ft. to the east of the line *A-B*, but at this distance of 87 ft. the ground is 25 ft. higher and the outcrop is still further up. A series of trial calculations must be made until a point is found where the horizontal distance

from the known line of strike AB

~~from *B*~~ multiplied by the ~~co~~tangent of the dip and added to the elevation of A or *B*, corresponds with the ground elevation. Such a point is finally found at *b*, and is marked on the ground and gives a point of the outcrop. At the south of *A*, the country is lower, and the vein outcrops to the west of the strike line *A*-*C*. At point *C*, the elevation is 902 ft. or 48 ft. lower than at *A*, hence the outcrop would be 48×cot 35 = 48×1.4281 = 68.5 ft. to the west of *C*, but here the ground is lower and the outcrop is still further west. A series of trial calculations must then be made until a point is found where the calculated position of the vein corresponds to the elevation of the ground.

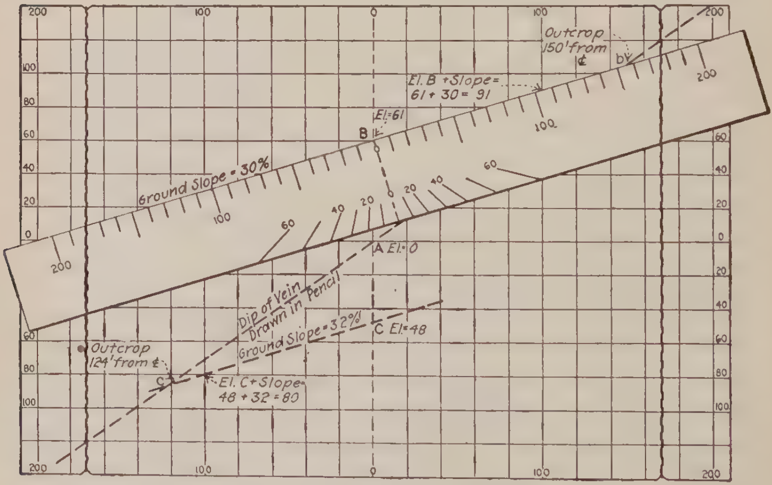

FIG. 81.—Slope stake diagram.

In the field, the surveyor would see that the outcrop must be up the hill from *B* and so might make his first approximation for the location of the outcrop for an elevation of 100 ft. above *A* and try that location. This would reduce the size of the next approximation and might enable the point to be located on the second trial.

If the slope of the ground is uniform on the line of any section, that slope can be measured, then in the triangle formed by the sloping lines and the vertical, as *A-c-C*, in the figure, the height *A-C* and the angles are known, and the triangle can be solved for the slope distance *A-c* which can then be measured off on the ground. Or the point of the outcrop can be determined graphically by a "slope stake diagram," as shown in Fig. 81. The point thus located can be tested by leveling if desired.

The "slope stake diagram" consists of a piece of cross-section paper mounted on cardboard and a cardboard ruler held to the diagram by two rubber bands about notches in the cardboard. The plane of the diagram represents a vertical cross-section on the line of the dip, the point *A* represents a point on the vein of known elevation, through which a line at the dip of the vein is drawn in pencil so it can be erased if the instrument is to be used for a vein with a different inclination. The ruler represents the ground. The vertical line through *A* represents a vertical plane on a strike line through some known point of the vein.

To determine the position of the outcrop on any section, locate the ground point on the vertical line at a distance corresponding to its elevation either above or below *A* as the case may be, then set the ruler through this point at the slope of the ground and the horizontal distance from the vertical line to the point of intersection can be read off the diagram, or if the ruler is graduated the slope distance can be noted. Thus the ruler is set in the figure for determining the point *B* and the dotted lines show the setting for the point *C* of Fig. 80. If the inclination of the ground is given, the ruler can be set at the proper angle by matching the protractor drawn along its lower edge with the vertical center line of the diagram. If slope of the ground is given, then the rise for 100 ft. can be added to the elevation of the center point and the outer end of the ruler can be set on this point on the line headed 100 ft. In railroad and general construction work a similar problem occurs in finding the intersection of the side of an excavation or of a fill with the surface of the ground. These lines of intersection in railroad work are marked by slope stakes and show the limit of the work. The little instrument just described was originated for this work, and hence its name.

VARIOUS PROBLEMS AND SOLUTIONS

1. **Boundary Lines.**—In keeping track of the position of the workings with respect to the boundary lines it has been suggested that the boundary line be used as a base line with a point of origin located on it, then one of the coordinates of every station would represent the shortest distance from that point to the boundary and the other would give the distance along the boundary of the station from the origin.

If the origin of the regular mine survey has not been placed on the boundary, a traverse could be run from some survey station to a point on the boundary and the survey in the part of the mine near the boundary could be recalculated for the new origin and base line.

2. **Driving a Connection.**—At a coal mine near Mount Carbon, W. Va., it was desired to prolong a certain room *A*, through to the outcrop in order to improve the ventilation, and to drive the connection from both ends. The map showed that a ravine cut into the hill opposite this room and so left only a short distance to be driven, see Fig. 82.

A new survey had to be run to get the necessary information. It started in the room *A*, went down the gangway and through a drift, and then along a trail that followed the outcrop. Sta. 45 to 21 were points from previous surveys. Sta. 57 was at the mouth of the drift. An older meander survey along the outcrop is shown by the dotted line near the traverse from Sta. 57 to 66. This had not been run with great care and could not be safely utilized for locating the connection. The figure only shows the part of the mine workings that interested the surveyor on this particular work.

For the calculations, Sta. 45 was taken as the origin and the line from Sta. 45 to 24 down the center of the room, which was to be the center line of the new connection, was taken as the base line with an assumed bearing of south. Then the coordinates gave the distances from Sta. 45 and when a zero departure was reached on the traverse it was evident that the base line and the center line of the new connection was being crossed, which

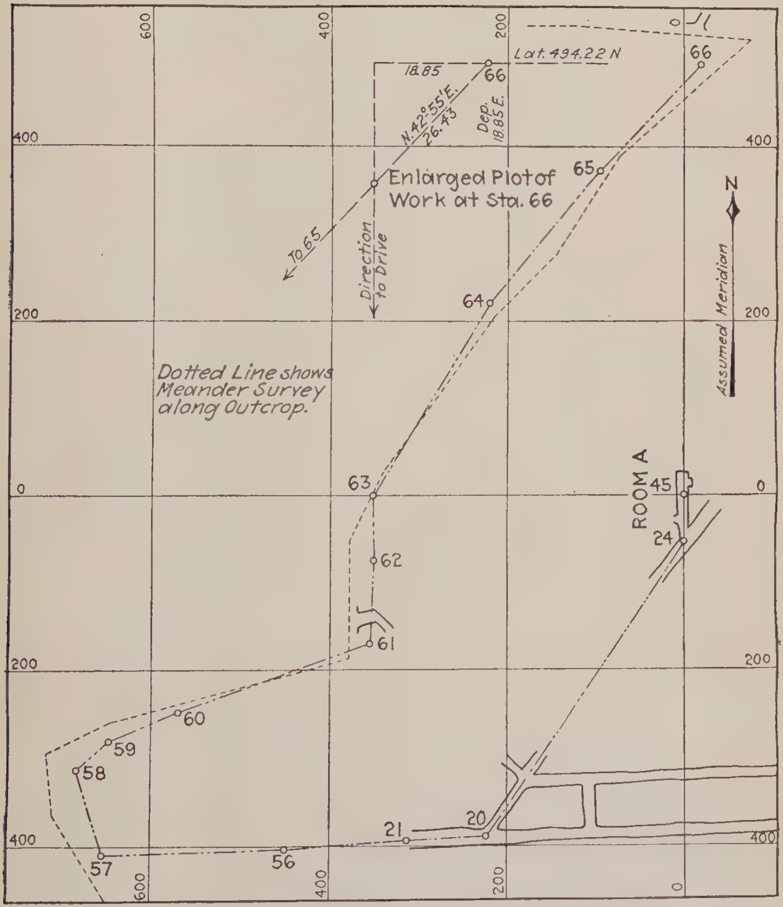

FIG. 82.—Survey for a connection on a fixed line.

occurred between Sta. 65 and 66. The coordinates of Sta. 66 were found to be N. 494.22 ft. and E. 18.85 ft. hence it was a simple matter to set up at Sta. 66, measure back $18.85 \div \sin 42°\text{-}55' = 26.43$ ft. and set a station in line with Sta. 65, as shown in the enlarged plot. This new station was on the line of the proposed connection and by turning off the proper angle, the direction was given for driving the new drift.

3. **Location of Workings on Surface.**—Occasionally it is necessary to lay out the mine workings on the surface in order to show the relations of the workings to a boundary or to surface objects. Usually the end or faces of the workings are all that are needed, and a random survey can be run by any convenient route from the origin to near the desired position, then the horizontal direction and distance of each of the survey stations near the face can be calculated and set out, and as much detail as desired can be reproduced from these end stations. If the positions of the desired stations are shown on a large scale plot, and the random survey is added to the plot as fast as it is made, the most advantageous position for the traverse stations will be indicated and if great accuracy is not required the direction and distance to the required points may be determined by scaling from the plot.

4. **Shaft Driven from Several Levels.**—The Franz Josef shaft at Przibram, Austria, was extended downward by working at several levels simultaneously. The position of the shaft with respect to two other shafts was determined on the twelfth level; then cross-cuts were driven on the seventeenth, the twenty-third, the twenty-fifth, the twenty-eighth, and the thirtieth levels to the site of the shaft; the shaft was excavated for the full size on each level, and the masonry lining was built as the work progressed. As soon as the shaft was finished between any two levels, the survey for that section was checked. All survey work was repeated and the resulting work was so accurate that no change in the lining of any part of the shaft was required.

5. **Shaft Sunk to Join Another.**—The San Francisco shaft of the New Almaden mines in California had been sunk from an adit

level, 240 ft. below the surface, to a lower level called the 600-foot level.[1]

It was required to locate the position of the lower shaft on the surface so a shaft could be sunk to connect with it and make one continuous shaft. The survey was run as shown in Fig. 83, from Sta. 5 in the adit tunnel out to the surface and up over the hill to near the site of the new shaft. At Sta. 5 radiating sights were taken to the four corners of the shaft and their coordinates were calculated, then when the survey reached the point S, the bearing and length of the lines from S to each of the four corners were calculated and laid out on the ground for starting the shaft.

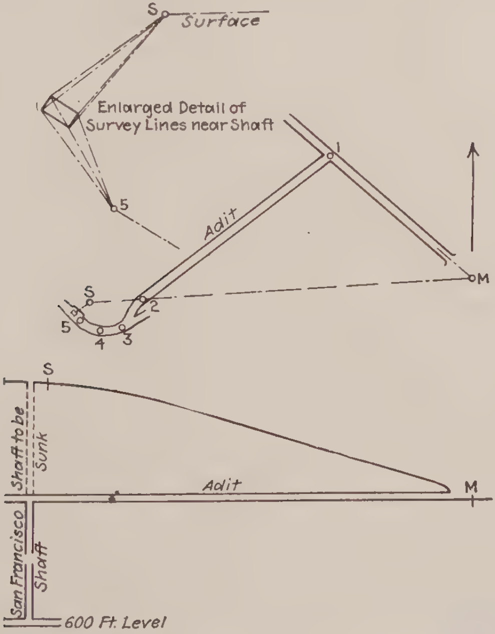

FIG. 83.—Survey for sinking a shaft to join another.

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[1] Abstract from "A Mine Survey," by J. F. Williamson, *Trans. A. I. M. E.*, August 1900, Vol XXX, p. 693.

The survey angles were read by repetition, the taping was done with great care, the levels were obtained with a Y-level and all the survey work was repeated using different methods for the check survey so as to eliminate personal errors. The new shaft was timbered as fast as it was sunk and it lined up satisfactorily with the lower shaft when the connection was made.

CHAPTER IX

VARIOUS MINE SURVEYING INSTRUMENTS

The study of early surveying instruments is interesting from an historical point, but their consideration is more valuable as indicating what may be done by a surveyor with simple or home-made apparatus in an emergency.

STRINGS AND TAPES

The use of these articles for surveying was developed before the value of the compass was appreciated, or the method of measuring angles by arcs had been discovered. In Agricola's "De Re Metallica," printed in 1561, and describing the mining and ore treatment of that time, is an illustration, Fig. 84, of a man determining the distance to be driven to connect a shaft and a tunnel. A cord has been stretched between the mouth of the tunnel and the top of the shaft, a plumb-bob has been let down the shaft from the top end of the inclined cord, a short horizontal cord has been stretched across these two, and the surveyor is engaged in measuring the three sides of the triangle thus formed. Then by measuring the inclined cord, the horizontal and vertical lengths of the proposed tunnel and shaft can be calculated by the principle of similar triangles.

This method of measuring the angle between two tightly stretched cords is the most accurate means of obtaining angles without an instrument. Thus, a cord can be stretched along a mine drift, offsets can be taken to the walls from it, and at a point where the direction changes, a tie line between points at known distances from the angle in the main cord gives means of calculating or plotting the angle. Usually such surveys are plotted by constructing the angles and scaling off distances without calculation. Where the intersection angle is large, one cord should be prolonged beyond the station and the deflection angle measured. If the distances from the angle to the two points on the strings are equal, then the tie between them is a chord of a circle and it is easy to calculate the angle, but where the angle is plotted without calculation, it is unimportant whether the sides are equal or not.

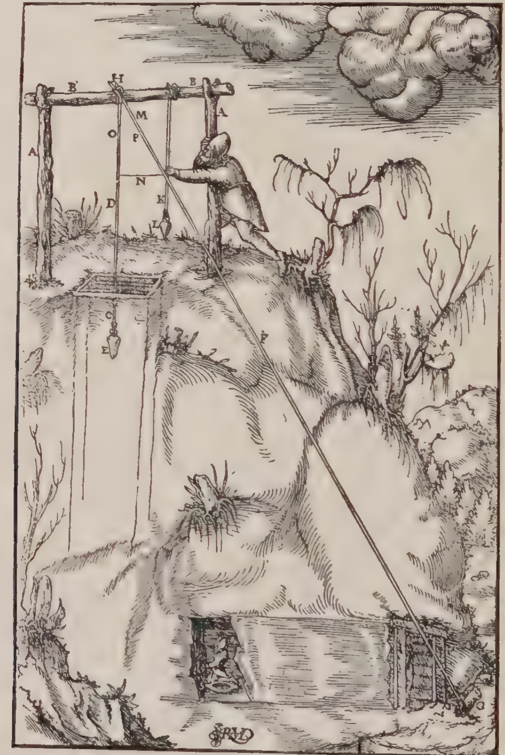

Fig. 84.—Cord survey. From "De Re Metallica" by Agricola, 1561.

On surface, quite accurate surveys can be made by the use of range poles and tapes, the angles being determined by measuring the diagonal distances across the fields so as to divide the area into triangles. In a mine, the walls interfere with long diagonal measurements and the small triangles that are available have to be accurately measured or gross errors will result when the larger similar triangles are plotted, hence the necessity of using cords.

This type of survey might be called *geometric surveying* and in various forms is very old; many designs of triangular sighting boards, for constructing similar triangles in obtaining the distances to inaccessible points, are illustrated in old books.

PLANE TABLES

The plane table was invented by Johann Prætorius in 1590,[1] in practically the form in which it is used to-day. It was used in the survey of Swedish mines.

On surface, the plane table can be used to develop a map, by orienting the last course on the board so that it will be parallel to the back course on the ground and then sighting and drawing the forward course and laying it off to scale. The method is hardly applicable to underground surveys on account of the wet, dirt and darkness.

A small plane table, however, may be used to graphically record the angles between any two courses, by drawing a line on the sheet in the direction of the last course and another intersecting it and in the direction of the forward course. The sheet with these angles on it is then used as a protractor to transfer these angles to the map.

This class of surveying might be called *graphic surveying.*

The instruments may be all home-made, the top may be any flat board, the support may be a camera tripod or a tripod like that in Fig. 97 [2]and the alidade may be a wooden ruler with a wire or a long fine nail projecting up at each end for the sights. The latter should be in line with the ruling edge of the alidade. Brass alidades with sights, like compass sights, are shown in instrument makers' catalogues and a study of them will suggest methods of improvising an accurate and convenient appliance.

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[1] "Topographical Surveys, their Methods and Value," by J. L. Van Ornum, *Bull. Univ. of Wis., Eng. Series,* Vol. I, No. 10, Dec., 1896. Abstract in *Trans. A. I. M. E.*, Vol. XXIX, p. 936.

[2] Or one similar to Keuffel & Esser Co.'s tripod No. 5351.

Early in the 1700's Brig. Gen. James Douglas invented and described an ungraduated instrument which he called the "Infallible."[1] It was a square copper plate to which a sheet of paper could be fastened. At the center of the plate was a pivot about which two rulers were free to revolve. Each ruler had a sight vane at each end. The instrument was used by sighting one ruler along the backsight and the other along the foresight and marking their position on the paper together with the necessary index marks to identify the sights.

A similar instrument was invented by James Henderson of Cornwall, England, in 1892, and called by him the "Rapid Traverser."[2]

The sight vanes on this instrument are pointed in the proper direction and their directions are recorded by marks on an enameled zinc plate which is later used in the office as a protractor in plotting the map. The marks on the enameled surface are not affected by water or ordinary rubbing but they can be scoured off and the plate can be used repeatedly.

Both the traverser and its predecessor are operated on the plane table principle of recording the angles graphically without noting their size by any system of measurement.

COMPASSES

The invention of the compass is very old and the credit for it is uncertain, but its use for mine surveying is first recorded in an anonymous German treatise on mining in 1505.[3] This compass had a wooden dial divided into twice twelve hours.

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[1] *Trans. A. I. M. E.*, Vol. XXIX, p. 933.

[2] Made by E. T. Newton & Son, Camborne, Cornwall, England.

[3] *Trans. A. I. M. E.*, Vol. XXIX, p. 932, and Vol. XXXI, p. 35.

The next improvement was the *setz-compass*, of which specimens bearing the date of 1541 are in existence.[1] This instrument consisted of a compass box 5.5 cm. in diameter, set in the center of a wooden disc 16 cm. in diameter and provided with three concentric rings of wax of different colors. A meridian line was scribed on the bottom of the compass box. The whole instrument was mounted on a staff. When in use, the needle was brought in line with the meridian, and then pointers were revolved into the direction of the course, as near as could be judged by the eye and a mark was made on one of the wax circles and a key number added to identify the sight; thus the compass was used to orient the instrument and the angles were recorded graphically. An entry of the length of each sight was made in a note book and numbered to correspond with the angle belonging to that sight.

For a long time the variations of the compass were not detected and even after discovery no attempt was made for some time to correct the reading.

English Compasses.—In England the compass has always been a favorite instrument for mine surveying on account of its convenience, notwithstanding its inaccuracy.[2] The type for mine surveys is called the Dial.

The dial of about 1800 consisted of a box compass with its sight vanes and having a clinometer on its cover. The ball and socket joint was slotted at one side so that the compass could be turned vertically and an inclined sight could be taken through the vanes, when the plummet indicated the vertical angle.[3] The clinometer on the cover was soon replaced by movable sights and a vertical arc on the instrument, and the plummet was superseded by an arm which pointed to zero when the instrument and its sights were level, see the early Hedley dial, Fig. 85. The vertical circle on this dial was arranged in various ways by different makers. Fig. 86 shows a modern one without a clinometer and Fig. 87 shows a more elaborate one with a telescope.

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[1] *Trans. A. I. M. E.*, Vol. XXVIII, p. 693.

[2] In "determination of and use of the magnetic meridian in mine surveying," *Trans. Fed. Inst. of Min. Eng.*, England, 1896, Vol. XII, p. 581. R. F. Percy, advocates the use of the compass to determine the meridian, and describes precautions and methods of repeating so as to eliminate the errors of local attraction in any one line. The meridian so obtained is to be used as the basis of the theodolite traverse.

[3] *Trans. A. I. M. E.*, Vol. XXVIII, p. 692.

The early Lean dials were nearly contemporaneous with the Hedley dial. They were fitted with telescopes and are thought to be the first mine surveying instruments to have them. They were slow in being adopted on account of their expense. Fig. 88 shows a modern pattern with sights, which can be removed and be replaced by a telescope.

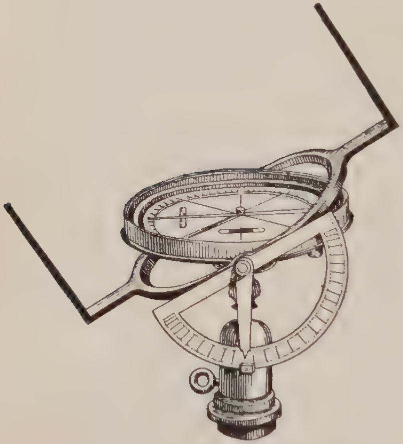

Fig. 85.—Early Hedley dial.

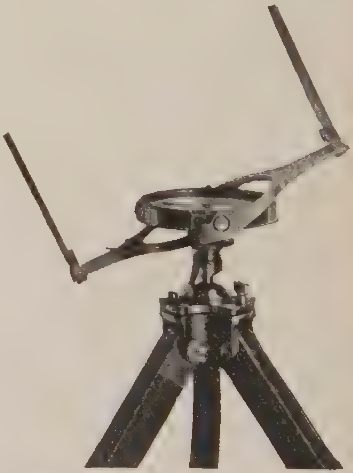

Fig. 86.—Recent Hedley dial without clinometer. Made by John Davis & Son, Derby, England.

Some of the modern dials have horizontal circles so angles can be read without the compass, and while they are quite elaborate, they retain the compass as an important and distinctive feature.

The process of using the dial was called *dialling* and the term has been continued in England to describe any kind of angle measuring, when the compass and magnetic needle are used, it is called *loose needle dialling* and when the needle is not employed and the angles are measured by the arc, it is called *fast needle dialling.*

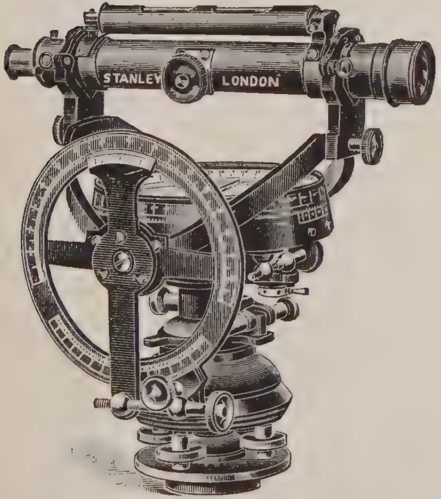

FIG. 87.—Modern Hedley dial, with telescope. Made by W. F. Stanley & Co., London, England.

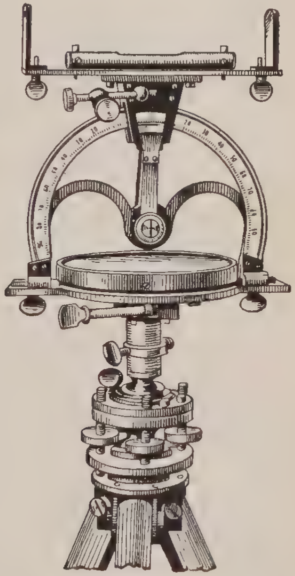

FIG. 88.—Lean dial with sight vanes.

Compasses in Mines.—The compass is a poor instrument for general mine surveying. It is, however, useful for filling in details in narrow or crooked workings where the compass lines can be tied into the transit survey at intervals, and errors are not allowed to accumulate. It is also valuable for making a rapid survey, as in mine examination, where a fair map is needed to describe conditions, but where no great accuracy is required.

Local attraction is common in mines due to magnetic minerals in the rock, to iron and steel objects lying about, to electric current in wire or rails and to stray currents through the rocks; this makes the compass readings particularly unreliable, unless the bearings are taken on both the back- and foresights and the difference of the two sights is taken as the angle. This difference will probably be within 1° of the true angle in extreme cases and the average error will probably be less.

For underground work, the compass must be arranged to take steeper sights than are possible with the ordinary land compass, and must have means for measuring vertical angles. Many of the "clinometer compasses" used in geological work have means for measuring inclinations when laid on their sides, but they are not applicable to steep sighting as they are made.

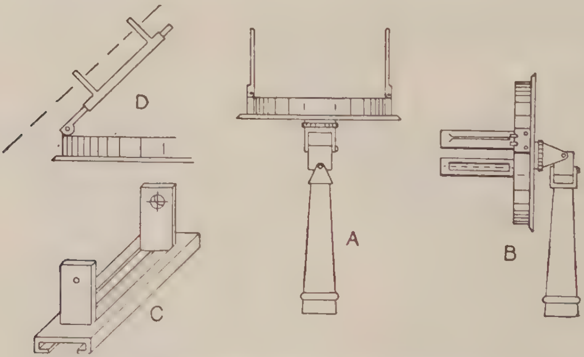

FIG. 89.—Compass altered for inclined sights.

Fig. 89 shows how one engineer changed a geological compass so as to adapt it to mine surveying.[1]

A universal joint was fitted to the tripod head for holding the compass which allowed the compass box to be turned into the vertical position, as in *B*, then inclined sights could be taken through the vanes and the inclination read by the pendulum attached to the center of the compass. In taking the bearing of lines, the compass box has to be horizontal and on steep lines as ordinarily arranged, the line of sight would strike the box. To overcome this, a slide *C* with two sights on it was made and slipped on one of the sight vanes, as in *D*, where it could be tipped to the desired amount for the sight. One of the sights on the slide had a pin hole for the eye end and the other had a larger hole with cross-wires. The slide could be slipped either way on either vane and be used to sight either up or down. It was usually used on the forward or open vane. It would have saved changing the slide if it had been provided with a double set of openings, so sights could have been taken through it from either end. The center of the slide was cut away, and so did not interfere with flat sights through the vanes. The tripod had extensible legs. They were each made of two rectangular strips of hardwood 1 by $1\frac{1}{2}$ in., with $\frac{3}{16}$-inch slots along their center lines, and were held together by two brass bolts working in the slots and provided with wing nuts.

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[1] "A Simple and Convenient Instrument for Mine Surveys," by Frank Robbins, *Trans. Can. Mining Inst.*, Mar., 1901, and *Can. Min. Rev.*, Feb., 1901.

Hanging Compasses.—Following the scheme of surveying a mine by stretching cords through the workings and measuring the angles between them by tie lines, the Germans developed a compass that could be hung from the cords and so determine their bearings. This is called a hanging compass and is useful in making surveys in cramped or crooked places, especially where the ends of the compass survey can be tied into the transit surveys and the information gathered is used to fill in other surveys.

The general scheme of surveying is to stretch stout cords along the drifts between stations and hang the compass, Fig. 90, from them and read the bearings. The hooks on this compass correspond to the sights on an ordinary compass and are on the north and south line. The compass is set in gimbals so that it always hangs level. The cord may be tied to timbers wedged across the drifts or attached to brass pegs driven or screwed into the mine timbers. The bearing can be read at both ends of the cord and thereby detect local attraction. Where the local attraction is serious, an extension bar may be used that hangs from the cord and holds the compass under the station point, as in Fig. 91, then the bearings of both lines can be read exactly at the station. This attachment is not often necessary.

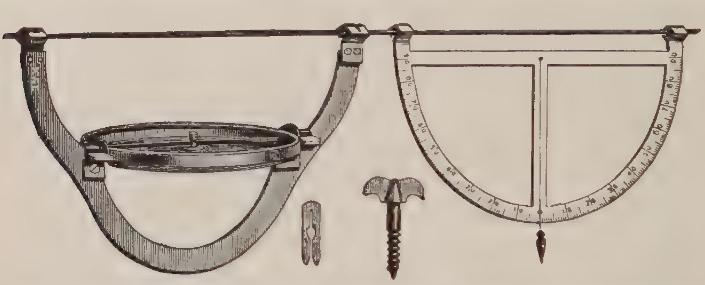

Fig. 90.—Hanging compass and clinometer. Made by Keuffel & Esser Co., N. Y.

The inclination of the cords is measured by a clinometer Fig. 90, which is of very light construction so as to avoid sagging the cord and thus altering the slope. The clinometer

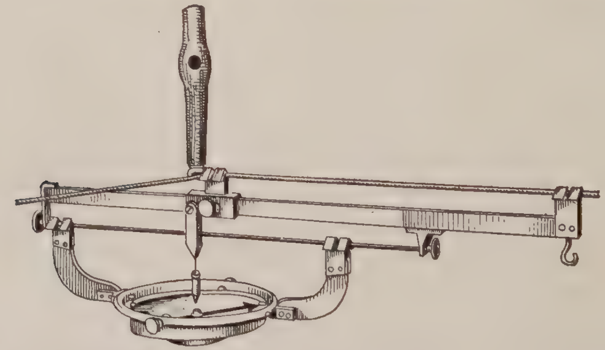

Fig. 91.—Extension bar for hanging compass, of German make.

consists of a semicircle of about 4 in. radius to whose center is hung a tiny plumb-bob by a fine cord. In whatever position the arc is placed, the plummet hangs vertically and the position of the cord across the scale indicates the inclination. In spite of the lightness of the clinometer it causes some sag and since every cord hangs in a catenary, the slope of the cord at either end is not the true inclination of a line between the stations. A near approach to the true inclination is obtained by measuring the inclination at each end of the span and averaging the readings, taking into account the sign of the inclination, or by placing the clinometer at the center of the span.

In 1868 Prof. Albert Miller von Hauenfels investigated the measurement of inclinations by the clinometer in the cord system of surveying and pointed out that the inclination of a cord at its center was not the same as the inclination of its chord, as the curve was a catenary and was not symmetrical, but that discrepancy was small.[1] He further noted that the shape of the clinometer caused more than half of its weight to come on the upper hook, and so depressed the cord and made the reading of the inclination smaller than it should have been, but by moving the clinometer a short distance up the cord from the center, a point could be found where the inclination as read would be the true inclination of the straight line between the ends. The spans experimented on were between 20 and 45 ft. long, the clinometer weighed about 7 oz., the tension used was about 45 lb. and the inclinations were from 2 to 76 degrees. He drew the conclusion that: "To read the vertical angle as accurately as possible the clinometer should be suspended toward the higher end of the cord at a distance from the center obtained by multiplying the length of the cord, at angles up to 15°, as read at the center, by 0.004 for each degree and for larger angles by 0.003." This rule would not hold with a different clinometer or a different tension in the cords, and new constants would have to be determined experimentally.

The hanging compass has been used in the iron mines at Longdale, Va., to survey the tortuous chutes and sub-drifts.[2]

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[1] *Trans. A. I. M. E.*, Vol. XXIX, p. 998.

[2] "Methods of Working and Surveying the Mines of Longdale Iron Co., Va.," by Guy R. Johnson, *Trans. A. I. M. E.*, Vol. XX, p. 96, and Vol. XXII, p. 543, and discussion by J. E. Johnson, Vol. XXIX, p. 993.

The system of mining was to drive car levels along the deposit, at intervals of 120 ft. vertically, to put in a chute and a manway about 120 ft. apart; from these to drive drifts every 10 ft. vertically in both directions and then to mine out the ore between the drifts by a caving system. The car levels were surveyed with a transit and a nail was located at each end of each chute or manway, then a cord survey was run through the chutes from one level to the next. The great variation in the dip of these chutes from almost nothing to the vertical is shown by the two sections, Fig. 92. The positions of the cords are shown by the dotted lines. The car levels were leveled and the elevation of the rail was noted opposite the top and bottom of every chute. These gave reference points for elevations in running the chute surveys.

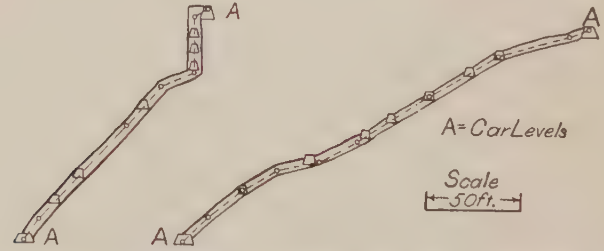

Fig. 92.—Survey of chutes at Longdale, Va., using a hanging compass.

The method used for surveying the chutes was, beginning at the lower end of the chute, to measure the height from the rail to the nail left by the transit survey; to tie one end of the cord (which was a $\frac{1}{8}$-inch braided linen line, wound on a light reel) to the nail; to carry the reel forward as far as possible keeping the line in the center of the chute; to fasten a light stick across the chute and attach the cord to it; to measure the bearing of the cord with the hanging compass, its inclination with the clinometer and the distance along it with a steel tape; to note the location of the center of any drift that was passed, and the height from the floor to the cord at its center line; to unfasten the cord, bring up the rear end and fasten it to the stick just used to hold the forward end; then to advance as far up the chute as possible, put in another stick, fasten the cord and repeat the operations. This was continued until the next level was reached, when the line was tied into the nail left there by the transit survey. Where the chute was vertical, the plummet was used.

The drifts were subsequently surveyed with the compass on a tripod; the compass was set up in the center of the drift as far in as a light held in the center of the entrance could be seen, and a light was carried forward as far as could be seen from the compass, then the bearings back and forward were taken. The compass was then moved two stations ahead and a backsight was taken on the light just used as a foresight and which had not been moved. This saved one-half of the set-ups and eliminated errors due to not setting the compass exactly over the point occupied by the signal.

The chutes were very crooked, and sometimes so small that a man could hardly crawl through them, and they were from 120 to 220 ft. long. The ore was non-magnetic and there was no iron in the chutes or on the levels. The survey was reduced to the vertical and horizontal by means of a "trigonometer" thereby saving a good deal of calculation. The hanging compass was provided with sights and was arranged so that it could be screwed on to a tripod; thus it could be used in surveying either the chutes or the drifts.

The compass surveys were made rapidly and gave ample data for plotting the progress of the work and for the details on the general map of the mine.

In some of the mines in the Transvaal, the hanging compass has been used to measure the stopes at the end of each month.[1] The method consisted of making a compass survey along the stope face from one level to the next, the survey being carried where possible from a traverse station in the drift above to another in the drift below. A linen tape was held with the zero mark at the rear station, while the forward man carried the box and went as far as possible. A candle mark was made on a stull, and the tape was held to it. The surveyor hung the compass on the tape, preferably near one end, so that the sag did not cause the tape to touch the foot wall. If the inclination was steep, the compass was prevented from sliding by a pin stuck through the tape. The bearing was noted. The clinometer was hung on the tape at the bottom of the sag, the tape being held taut, and the inclination was read to the nearest degree. Offsets from the main tape to the stope face were then taken at intervals, an assistant holding one end of a short tape against the wall and the surveyor holding the other end and keeping the notes. On reaching the end of the main tape, its length was read and recorded. The rear man then dropped the tape and it was wound up. The survey was carried in this way from stull to stull. The ends of the survey at both the top and the bottom levels were marked by a tin tag nailed to a stull and having a number stamped on it. These were used as the start and finish of the surveys for the next month.

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[1] Abstract of notes by C. A. Newton, 1911.

In the office, the transit survey stations were plotted to a large scale on a sheet, the magnetic meridian was drawn on it, and then the compass survey was plotted with a protractor after the distances had been reduced to the horizontal by means of a traverse table. A separate sheet was used for each stope. The area stoped was measured with a planimeter. This, being the horizontal area, had to be multiplied by the secant of the dip, to get the area of the vein that had been stoped. The dip was determined from the difference in elevation between the top and bottom of the stope and the horizontal distance as scaled from the map in a direction normal to the average strike of the vein.

CIRCULAR MEASUREMENTS OF ANGLES

When the defects of the compass had become thoroughly impressed on the German mine surveyors in about 1700, they attempted to measure the angle between the adjacent cords stretched in a mine, by an instrument called an *eisenscheibe*, or iron disc. This received its name from the fact that it was adapted to the surveying of iron mines, where the local attraction interfered with the use of a compass. It was a circular brass plate graduated, in the early instruments, into 24 hours, and in later ones into degrees. It was provided, in some cases, with one arm and in others with two arms, movable about a center pivot; in the latter case, cords to adjacent stations were hooked, one into the end of each arm and on being drawn tight pulled the arms into line; the zero of the circle being set against the arm on the back course, the angle to the forward course could be read at the other arm.[1] One form of this instrument is shown in Fig. 93. The method of using this form is particularly interesting as cross-screws, similar to the one used to hold the instrument, were inserted for both the fore- and backsights, and then after the angle had been measured, the instrument was carried ahead and set on the forward screw, thus using the principle of the three tripod surveys. After the angle had been read, the inclination of the forward cord was measured with a hanging clinometer and its distance was taped.

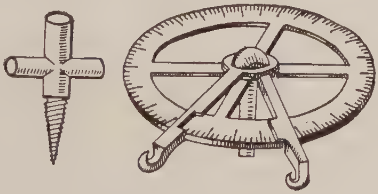

Fig. 93.—Möhling's eisenscheibe and support.

More elaborate and later specimens of the eisenscheibe had a vertical arc mounted to revolve about the center spindle and had the arm arranged to take the inclination of the cord, so that both the horizontal and vertical angles could be measured simultaneously.

The eisenscheibe represents an early form of angle measuring instrument which later developed into the transit and the theodolite. This method of surveying might be called the *trigonometric method,* as trigonometry was used in the reduction of the notes.

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[1] *Trans. A. I. M. E.*, Vol. XXVIII, p. 689, and Vol. XXXI, p. 931.

The circumferenter was described by W. & S. Jones of London in 1797,[1] but it was probably older. It had a compass in the center, a circle graduated in degrees to which was attached two fixed sight vanes, a movable arm pivoted at the center, with a

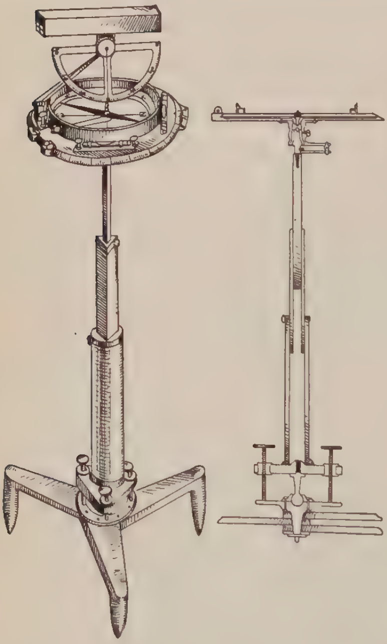

Fig. 94.

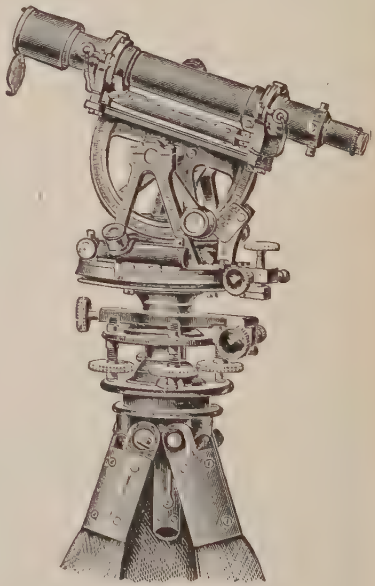

Fig. 95.

Fig. 94.—Breithaupt's first mine theodolite. (Courtesy of F. W. Breithaupt & Son, Cassel, Germany.)

Fig. 95.—English theodolite of Y-pattern. Made by Troughton & Simms, London, England.

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[1] *Trans. A. I. M. E.*, Vol. XXVIII, p. 695. Bennett H. Brough says that it was invented by Jan Pieterszoon Dou of Leyden in 1612, see *Trans. A. I. M. E.*, Vol. XXIX, p. 934.

sight vane at each end, and means for reading the position of the arm to five minutes of arc. When in use, the fixed sights were set on the back course, the movable ones were pointed on the forward course and the angle between the courses was read on the arc. After the movable sights had been set on the forward course, the sight on the back station could be repeated with the fixed ones and so test the setting of the instrument.

Some of the modern railroad compasses are provided with horizontal arcs for reading angles independent of the compass. They have only one pair of sights, which is used for both the back- and foresights, but they are capable of doing the same work as the "circumferenter."

An early step in the development of the modern theodolite is seen in the instrument introduced by H. C. W. Breithaupt of Cassel, Germany, in 1798, which may be called the first mine theodolite,[1] Fig. 94. The compass was surrounded by a graduated circle which could be read by verniers, the needle could be clamped when not in use, a clinometer was attached to the sighting tube and the whole was mounted on a sort of tripod. A sighting tube was used, for economy, instead of a telescope. The signal lamps, two of which were used, were interchangeable with the instrument on the tripod, or could be hung as a plummet.

From Breithaupt's instrument it is but a short step, by exchanging the sighting tube for a telescope and improving the details, to get one type of the modern English theodolite, as shown in Fig. 95. When the telescope is to be reversed by rotating it on its horizontal axis, as in the American transits, the vertical arc must be placed at one side of the telescope, thus changing another detail but still using the principle of Breithaupt's instrument.

LEVELING

A simple "A-frame" depending on a pendulum to plumb it, as shown in Fig. 96, can be used for leveling. The A-frame may be made with a spread of a rod or some other unit of distance, and then is convenient for laying out roads or ditches as it gives both levels and distances. Where the height of the A-frame is objectionable, a lower rectangular frame might be used but would not be quite so stiff for its weight.

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[1] *Trans. A. I. M. E.*, Vol. XXVIII, p. 693.

To graduate the A-frame, its feet are set on two stakes and the position of the plumb-line is marked on the cross-bar; it is reversed and the position of the plumb-line again marked; the distance between the marks is bisected and gives the position of the plumb-line when the feet are on the same level. The high stake can now be driven down until the plumb-line hangs on the center mark and the A-frame can be tested by reversing it. Other graduations can now be made on the horizontal bar for various grades by placing a block of the desired thickness on one of the level stakes and marking the new position of the plumb-line; thus a 2-in. block on a 16½-foot span equals a grade of 2 in. per rod. If desired, the horizontal bar can be graduated to read the inclination in degrees.

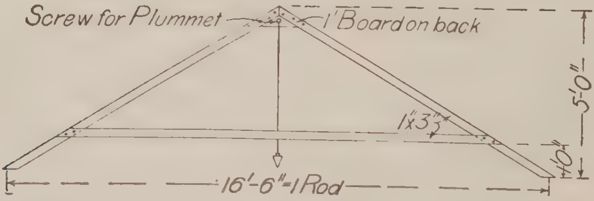

Fig. 96.—A-frame for leveling.

The water level, shown in Fig. 97, affords a means of making a simple level with which quite accurate work can be done, say with an error of less than one foot in a mile. The two glass tubes or bottles are connected below by a pipe and the whole apparatus partly filled with water colored with dye, bluing, ink or even mud. Corks are put in the tops of the tubes to prevent spilling the liquid while carrying the instrument. When the level is in use, the corks are removed allowing the liquid to come to the same level in the two tubes; it is pointed toward the rod so that the tubes appear to be about $\frac{1}{2}$ in. apart to an observer standing about 2 ft. back of the instrument and the leveling rod appears between the tubes, see *B* in the figure; then by moving the eye up or down, a position is found where the tops of the liquid in the two tubes will appear opposite each other and the point on the rod can be located where this level line strikes. A convenient rod for sur-

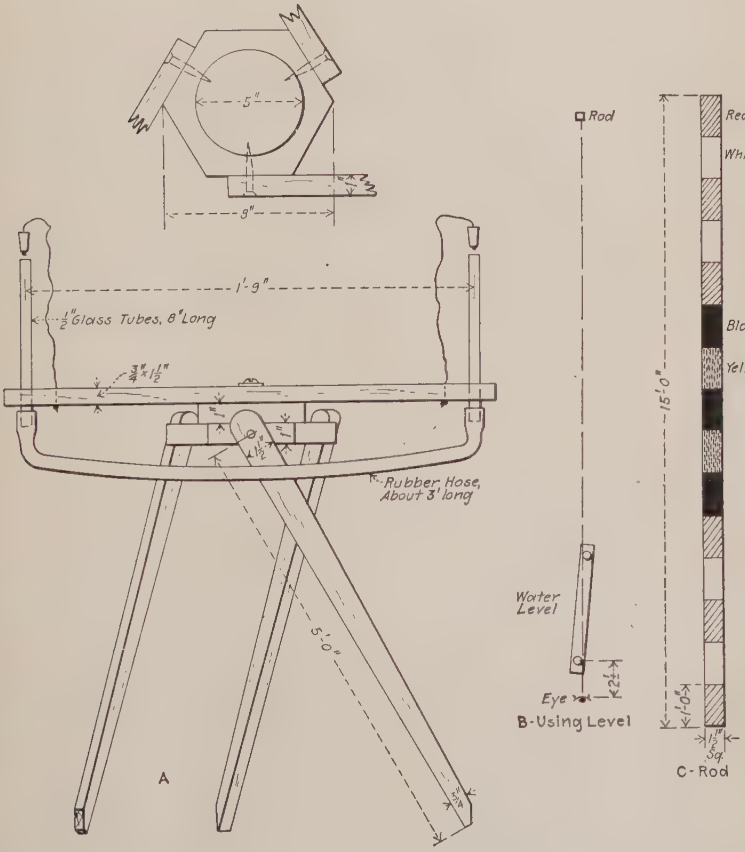

FIG. 97.—Water level, tripod and rod.

face surveys is one about $1\frac{1}{2}$ in. square and 15 ft. long, painted in alternate colors, each 1 ft. long. The color scheme shown in the figure is convenient, as the observer can read the rod as far as the colors can be seen. The readings can be estimated to 0.1 ft. without difficulty.

If used underground a short simple rod with provision for extending it, will be necessary. It may be graduated every 0.1 ft. with a single line, as the sights will be taken to a bar, held across the rod and illuminated by the rodman and its position will be read by the latter.

CHAPTER X

STEEP TRANSIT SIGHTS

In General.—In the surveying of the chambers or stopes of a mine it is usually possible to do all the work with the transit equipped for ordinary mine surveying, even when the workings are on a steep vein, as the sights can usually be taken diagonally and at a flatter angle than the dip. But in the case of mines that are entered by inclined shafts or slopes, where the alignment has to be carried down this opening, and in making connections from one level to another, it is often necessary to take sights that are so steep that the line of sight will strike the horizontal plates. These steep sights may be taken upward with any transit by using a prism eye piece, see Figs. 11 and 12, and they may be taken either upward or downward by using an eccentric telescope such that its line of sight will clear the plates. The eccentric telescopes are of two patterns, namely, the top telescope and the side telescope as shown in Fig. 98. They are attached to the main telescope and are usually a little smaller than the latter.

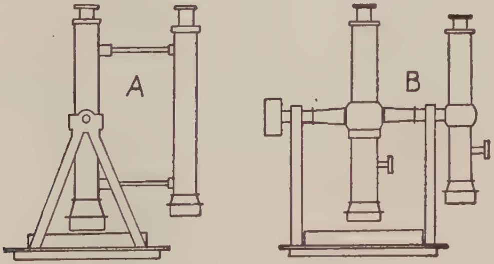

Fig. 98.—Top and side telescopes.

In taking steep downward sights, care must be taken in setting up the transit that the tripod legs do not come in such positions as to interfere with the line of sight through the eccentric telescope. This difficulty is avoided and in addition a very secure mounting is obtained by clamping the instrument to a plank or platform built across the slope. The transit is secured to a block of wood, in the same way that it is attached to the tripod head, the block having been previously fastened to the platform with screws. If a block is cut out of soft wood, round and the same diameter as the outside of the screw on the tripod head, it can be threaded by screwing the tripod cap onto it, and working the cap back and forth. This thread will last for some time, and when worn out another can be easily made. Instead of the block, the transit might be mounted on a trivet set on the platform, Fig. 99. A second platform should be provided for the surveyor to stand on, so that he will not jar the instrument platform.

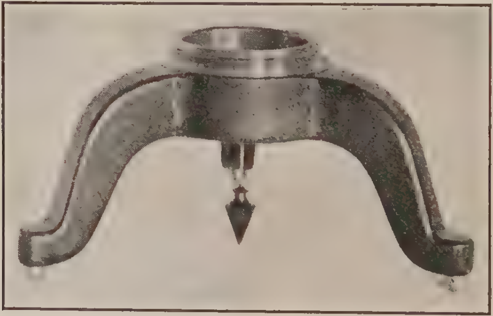

Fig. 99.—Trivet. Made by Buff & Buff Mfg. Co., Boston, Mass.

Another arrangement is to mount the transit on a metal bracket which is screwed into some of the mine timbers, Fig. 100.

Any of these arrangements are also useful for holding the signal, and they furnish the additional advantage over tripods, that in some cases they can be set high enough to allow the movement of cars or other travel under them. See page 243.

After the transit has been mounted on a platform or bracket, a plumb-bob can be hung through a hole in the support and a station point set in the floor under it as a record. These forms of support are more difficult to put back in the same place than a tripod, hence it is desirable that all the work at any station should be completed and the alignment transferred to more convenient points before the supports are removed.

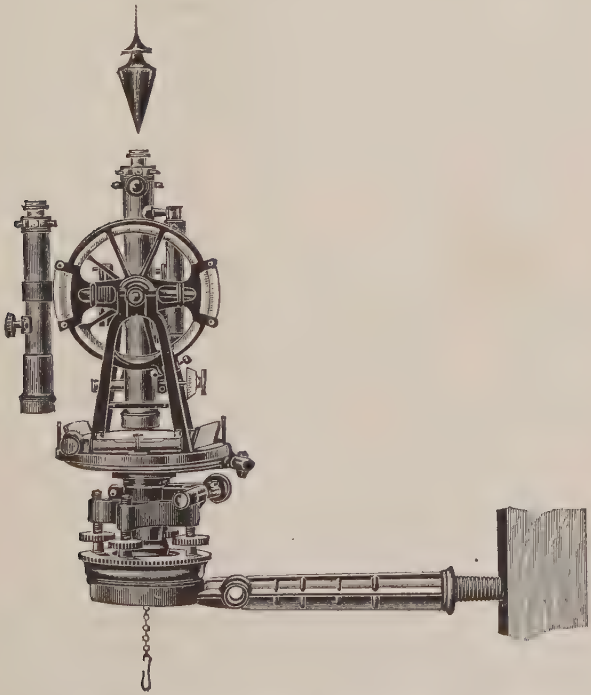

Fig. 100.—Bracket for instrument. Made by C. L. Berger & Sons, Boston, Mass.

The principle of the three-tripod method is well adapted to carrying a line down a steep incline where platform or brackets are used.

Adjustments of the Transit.—All the standard adjustments of the transit must be made as perfectly as possible, and in addition the horizontal axis must be specially tested through a large angle, so as to prove that it is truly horizontal when the main spindle is vertical, as shown by the bubbles. This may be done by setting the transit midway between long plumb-lines and on a line joining them. The plumb-lines may be conveniently hung from the cornices of two buildings. The transit should be leveled with the long bubble and its position be tested for line by sighting on one wire with the telescope level, plunging and sighting on the other.

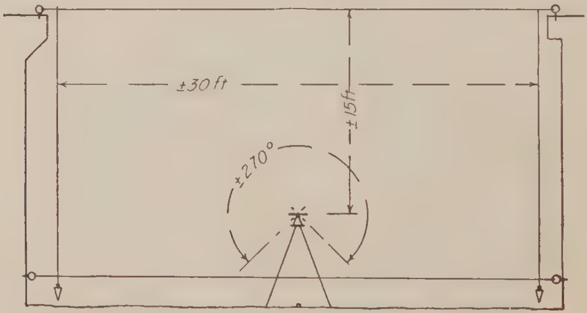

FIG. 101.—Special adjustment of horizontal axis.

This observation should be repeated with the telescope in the reversed position from that used for the first test. Wires are now stretched tightly between the tops and the bottoms of the plumb-wires, Fig. 101. The wires then outline the four sides of a vertical plane through the instrument. The telescope can now be rotated through an angle of about 270°, and should follow the wires throughout. If the line of sight departs from the wires, the adjustment of the horizontal axis must be improved. The two plumb-wires might be hung directly from the top horizontal wire, which would ensure their being in the same plane. It is evident that the best results would be obtained on a still day and with fine wires, that offer very small surfaces to the wind.

Measuring Steep Vertical Angles.—The measuring of steep vertical angles by any method is accompanied with some difficulty. If a flat sight is taken on a peg, a plumb-bob or a tripod lamp, it is easy to set the horizontal wire on the top line of the object but if the sight is inclined 30° or more, up or down, the object is distorted, especially when it appears as a black silhouette on an illuminated white ground as in mine work, and there is no way of distinguishing the point on which to sight, hence a special target must be prepared such that a definite horizontal line will be shown to the transitman. This can be accomplished by soldering a cross-wire to a vertical wire or to a surveyor's pin.

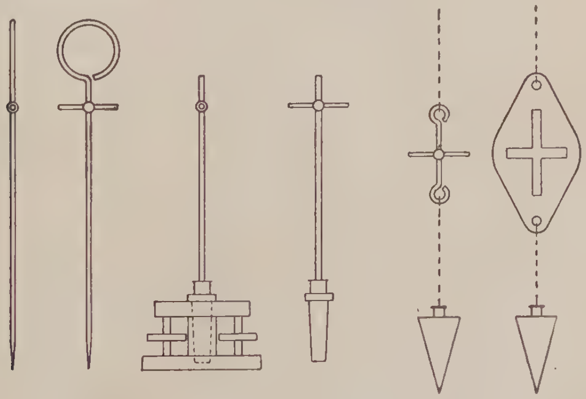

Fig. 102.—Targets for inclined sights.

Then by holding this on the point and placing an illuminated white surface behind it, a definite line is given the transitman on which to set the cross-wire, Fig. 102.

If the survey is being run by the three-tripod method, the vertical wire could be fitted with a socket at its lower end so that it would fit into the tripod in the same manner as the lamps. In this case it should be the same height as the transit or lamp above the joint, so as to be interchangeable, as explained on page 56.

If the survey is being run by the plummet method, a cross-wire or cross-shaped slot might be combined with the plummet, as a link in the cord, just above the bob. This must be watched to see that it does not twist around so that the instrumentman cannot see the cross.

TOP TELESCOPE

The top telescope is mounted on top of the main telescope by means of upright posts so that it is parallel to the main telescope, and vertically over it. It may be held by two rigid posts as in Fig. 103, which are designed by the instrument maker to hold the two telescopes in a parallel position, or there may be only a single support for the top telescope as in Fig. 111, which sometimes has a side adjustment.

Adjustments.—The vertical wire of the auxiliary telescope should be set truly vertical, as is done in adjusting the main telescope of the transit, by comparing it with a plumb-line or by sighting on a distant point and watching whether the point stays on the wire while the telescope is raised or lowered. Then each time the telescope is attached it must be tested to see, first, that it is in the same vertical plane as the main telescope and second, that the two lines of sight are parallel.

1. *To bring the telescope vertically over the main telescope.*—The main telescope is sighted on a distant plumb-line, and the vertical wire of the top telescope is brought on the same wire, by shifting the cross-wires when the standards are rigid or by moving the support when that is adjustable; or the adjustment can be made, if both vertical wires are truly vertical, by sighting on any distant object with the main telescope and shifting the wires of the auxiliary so that they will bear on it also; it is well to repeat this last method of adjustment on a near object. When the support is adjustable and the wires do not have to be moved, it is well to set the cross-wires in the center of the auxiliary telescope by placing it in improvised wooden Y's, pointing it on a distant object, rotating the telescope, and adjusting the wires as is done with the Y-level. The Y's should be so spaced that the telescope will rest on the turned ring on which the cap is placed and on the tube near the cross-wires.

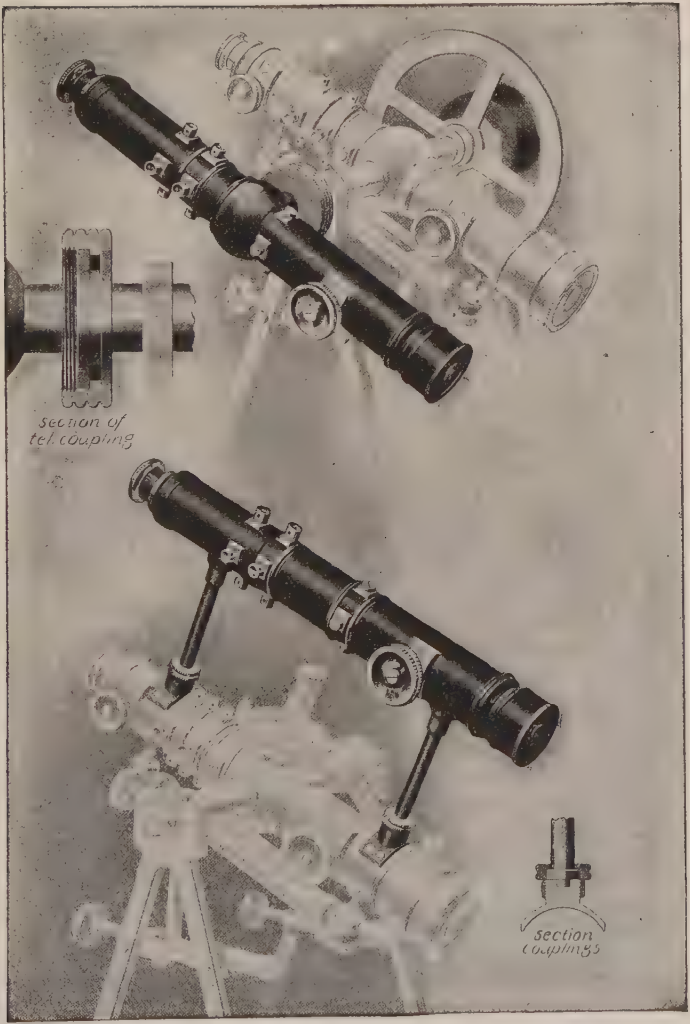

FIG. 103.—Top and side telescopes. Made by W. & L. E. Gurley, Troy, N. Y.

2. *To make the two horizontal lines of sight truly parallel.*—Both telescopes are sighted at the same time on a pair of targets, whose vertical distance apart is equal to the distance between the lines of sight of the two telescopes. This distance would be the vertical distance between the centers of the two telescopes if the lines of sight were in the center of both of the tubes, but as this may not be the case, the distance between the lines must be found by experiment. If the two telescopes are parallel and are sighted on a finely divided rod held at various distances the interval covered on the rod will be constant, but if the telescopes are not parallel, the interval covered will vary with each observation. Suppose the conditions are as shown in Fig. 104, then by similar triangles, the eccentricity can be found as shown in the calculation below the figure. The two targets will then be placed at this distance apart and the cross-wire of the main telescope will be set on the lower one and the cross-wire of the auxiliary will be adjusted to strike the upper one. The adjustment should be tested by holding the targets at various distances from the instruments.

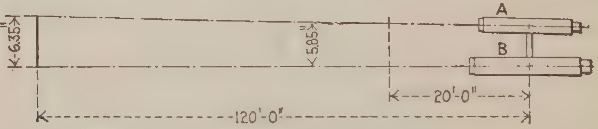

FIG. 104.—Determination of eccentricity. Divergence in 100 ft. is 6.35 −5.85 = 0.50 in. or 0.10 in. in 20 ft. making the eccentricity, AB = 5.85 −0.10 = 5.75 in.

As both wires in the auxiliary telescope have to be moved to make either of the above adjustments, the adjustments must be repeated alternately until both are correct.

The instrument should be tested under the horizontal wire with the top telescope and its counterweight in place to see that the extra weight does not affect the adjustment of the horizontal axis. If it should affect the action of the horizontal axis, the trouble can probably be remedied by cleaning the bearings, lubricating them sparingly with watch oil, and setting the cap of the bearings down quite firmly, so as to prevent motion.

If the top telescope is removed from the instrument after adjustment, in order to take it underground, the adjustment must be tested on the longest sight available in the mine after it is reassembled. This adjustment underground can be avoided by having a special carrying case made that will hold the instrument with the auxiliary telescope attached.

Measuring Horizontal Angles with Top Telescope.—Horizontal angles may be measured with the top telescope in the same manner as with the main telescope except that the telescopes must always be used in the normal position. If they were reversed, the top telescope would come under the main telescope and its line of sight would strike the plates sooner than that of the main one and the purpose for which it was intended would be defeated. This necessitates a very careful adjustment of the collimation as there is no chance to eliminate its errors by reversal.

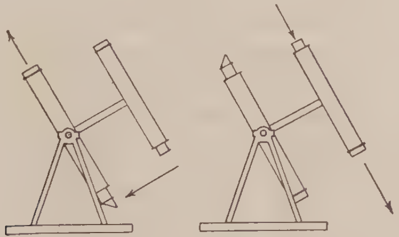

FIG. 105.—Alternate use of main and top telescope.

It is often convenient to take one sight of an angle reading with the main telescope and the other with the top telescope. This may occur where one sight has a steep upward inclination and the other is flat or downward. Then the prism eye piece can be placed on one telescope for the upward sight and the other telescope can be used with a straight eye piece. This will save altering the eye pieces in any angle reading and so remove the liability of jarring the setting of the verniers. The method is particularly useful in reading an angle between two courses in a steeply inclined shaft, where the main telescope with the prism eye piece can be used for the upward sight and the top telescope with the straight eye piece can be used for the downward sight, see Fig. 105. In these uses of the top telescope, in combination with the main telescope, the horizontal angle read is the true one and is the same as would be read by the main telescope used alone. The angle may be read by repetition except that the telescope cannot be reversed on half of the set.

The top telescope is valuable in producing a vertical plane through the center of the instrument, down a steep or even vertical opening and establishing two points in that plane at the bottom, as in Fig. 106, thus transferring a surface line to points underground.

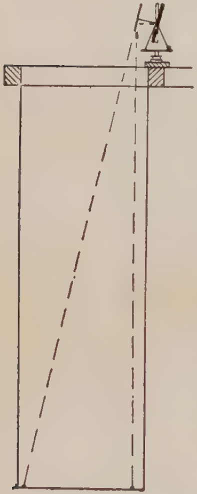

FIG. 106.—Transferring alignment down a vertical shaft with a top telescope.

Measuring Vertical Angles with the Top Telescope.—In addition to the difficulties of sighting on a target on any steep line mentioned on page 173, the top telescope introduces an error in the vertical angle due to its eccentricity.

This may be overcome by providing an eccentric target as in Case I, Fig. 107, such that the line of sight through the top telescope to the outer target will be parallel to the line through the center of the instrument and the real target, the latter being the line whose vertical angle is shown on the vertical circle. The distance measured from the center of either telescope to its target will be the inclined distance for which the vertical angle was read. This gives correct results with the usual calculations but a jointed target must be provided and the offset must be made normal to the line of sight.

A better method of measuring the vertical angles is to sight directly on the target with the top telescope, record the angle indicated on the vertical circle and then apply the correction for the eccentricity. Thus in Case II, Fig. 107, the line *b-c* is the sight taken with the top telescope and the line *a-d* through the main telescope is the parallel line whose inclination, A, is measured on the vertical circle. The distance will be measured from *a* to *c*, and the angle, B, will be the true inclination of this line. Then $B = A - C$, in which C is the error due to the eccentricity *a-b* and may be found by solving the triangle *a-b-c*, since

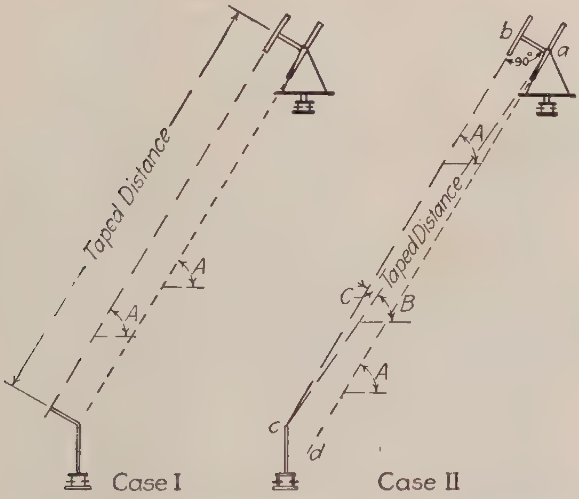

FIG. 107.—Vertical angle measured with a top telescope.

$\sin C = \dfrac{a\text{-}b \text{ (fixed)}}{a\text{-}c \text{ (measured)}}$. The inclined distance *a-c* can then be reduced to horizontal and vertical distances by means of functions of B.

If the vertical angle is downward or negative, the angle read by the top telescope sighted directly on the target will be too large but if the vertical angle is upward or positive, the angle read by the top telescope sighted on the target will be too small.

When the three-tripod method of surveying is being used, the vertical angle read from any station, A, forward to station B will differ from the true angle by the same amount as the vertical angle read from station *B* backward to station *A*. The difference, however, will be in the opposite direction, hence the true angle is the mean of the two angles, except when the stations are nearly on the same level, then the signs of the angles may be confusing, but with flat angles there is no need to use the top telescope, as the sight with the main telescope would not hit the plates. The amount of the correction should be calculated and applied to both readings of the vertical angle, when the inclination is read from both ends, so as to afford a check on the

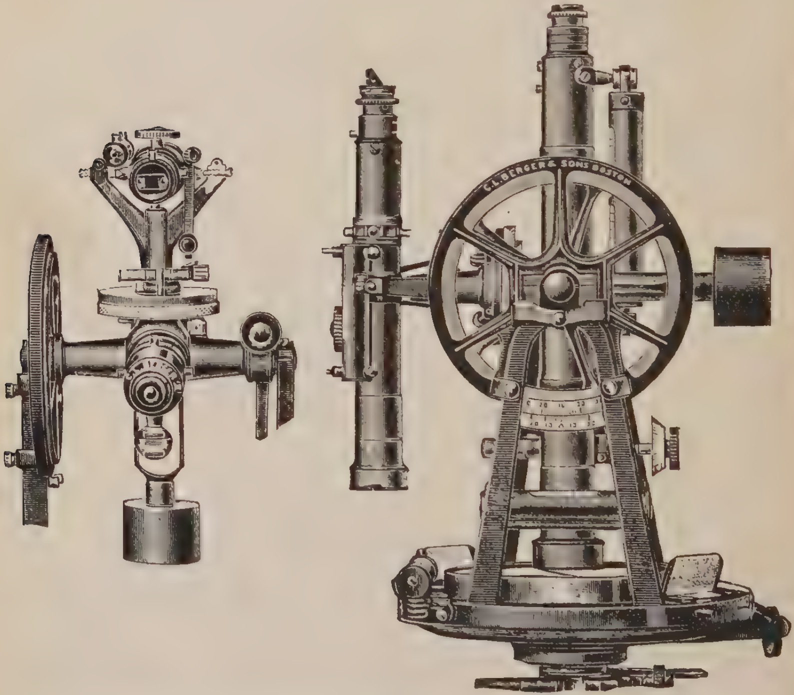
C. L. BERGER & SONS BOSTON

FIG. 108.—Solar attachment, used as an auxiliary telescope. Made by C. L. Berger & Sons, Boston, Mass.

instrumental work; if the two readings are averaged, there will be no check and errors in the readings may not be detected.

Use of the Solar Attachment as a Top Telescope.—The ordinary solar attachments of the Saegmuller type are not adapted for use as top telescopes, as they are small, of low magnifying power and cannot be brought into the same vertical plane as the main telescope.

A special solar attachment, shown in Fig. 108, has a telescope that is about three-fourths the length of the main telescope, is fitted with a 1-inch objective and has means of adjusting its horizontal axis sidewise so that it can be brought exactly over the main telescope. This attachment is capable of doing as accurate work as the ordinary top telescope.

SIDE TELESCOPE

The side telescope is attached to a boss on the end of the horizontal axis opposite the vertical circle. It is in a plane passing through the main telescope and the horizontal axis and is made parallel with the main telescope by the maker. The joint whereby it is attached is not usually adjustable, see Fig. 98-*B* and 103. The exact adjustment of the line of sight must be made each time the side telescope is attached by shifting its cross-wires, hence if it is to be used underground or where the adjustment cannot be tested, the instrument must be carried to the work with the side telescope attached, and after the work is done it should be brought back and be retested before its position has been disturbed. This will require a special carrying case.

Adjustments.—The main telescope must be adjusted as perfectly as possible and tested on the overhead wires as described on page 172.

The cross-wires of the auxiliary telescope should be brought into the center of the tube by placing it in improvised wooden Y's, pointing it on a distant object, rotating the telescope, and adjusting the wires to stay on the object as is done with the Y-level. The Y's should be so spaced as to let the telescope rest on the turned part outside of the objective where the cap is placed and on the tube near the cross-wires. The vertical wire should be made vertical by comparing it with a distant plumb-line, when the auxiliary telescope is attached to the instrument, or by pointing the wire on some object and on moving the instrument up and down, and watching whether the object stays on the wire or not.

Each time the telescope is attached the line of sight must be adjusted, first, so that it will be in the plane of the main telescope and the horizontal axis, and, second, so that the line of sight will be parallel to the main line.

1. *To bring both telescopes into the same plane:* Point the main telescope on some distant object, with the instrument perfectly level and the telescope horizontal and bring the horizontal wire of the auxiliary telescope on the point by rotating the telescope about the axis of the instrument at its clamp. This may be done by tapping one end of the auxiliary telescope with the finger before the clamp is screwed up tight, until the desired position is reached, when the clamp is screwed up firmly. If the object is close to the instrument the transit may have to be revolved about its vertical spindle in order to enable the object to be seen through both telescopes. If the auxiliary telescope cannot be shifted at its clamp, the line of sight of the auxiliary must be brought to the desired position by shifting the cross-wires.

2. *To make the two lines of sight parallel:* Point the telescope on a distant target and measure the distance between the lines of sight. Repeat this at a nearer target and calculate the distance between the lines of sight of the two telescopes as explained for the top telescope page 176. The eccentricity thus found must be laid off horizontally on the distant target, the main telescope pointed on one of the marks and the vertical wire of the auxiliary set on the other by its adjusting screws. This last adjustment may have affected the horizontal wire so the previous adjustment must be tested and remade if necessary. On extensive surveys, the adjustment of the auxiliary for parallelism with the main telescope should be tested during the progress of the work.

Placing the Telescopes at an Angle with each Other.—For some work, it may be desirable to place the auxiliary telescope at an angle with the main telescope; if so, with the auxiliary loosely clamped, the main telescope is brought to the horizontal, a mark is made on a distant wall, the main telescope is tilted through the desired angle, the auxiliary is brought to the mark, and then is clamped.

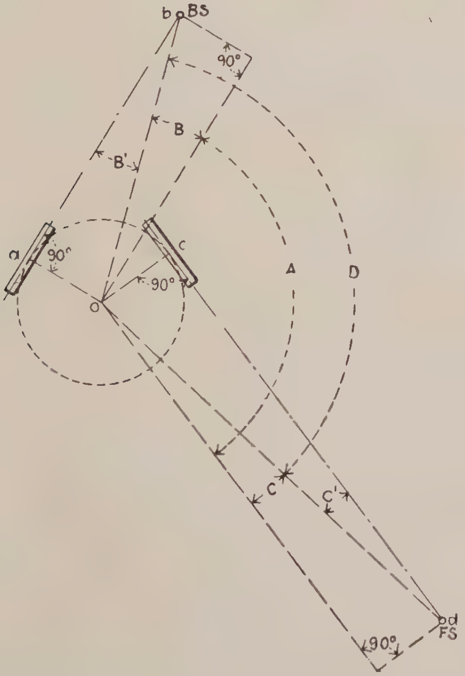

FIG. 109.—Horizontal angle measured with a side telescope.

Measuring Horizontal Angles with the Side Telescope.—The horizontal angles obtained by sighting on targets with the side telescope are not the true ones, both the back- and foresight being affected by the eccentricity. This error due to eccentricity can be calculated and the angle as read can be corrected. Thus in

Fig. 109, let *o* be a transit in plan, let the side telescope be sighted in succession on the backsight and on the foresight, and let the distance from the center of the side telescope to the target be measured and reduced to the horizontal. Then the angle shown on the plates will be the angle, *A*, being the angle between the two positions of the main telescope when the side telescope is pointed on the targets. The true angle, $D = A + B - C$, but B and C are the same as B' and C' and these can be found by solving their triangles, of which the eccentricity and the horizontal distances are known. In this case, this gives,

$$\tan B = \frac{a\text{-}o \text{ (eccentricity)}}{a\text{-}b \text{ (horizontal distance)}} \text{ and } \tan C = \frac{c\text{-}o}{c\text{-}d}.$$

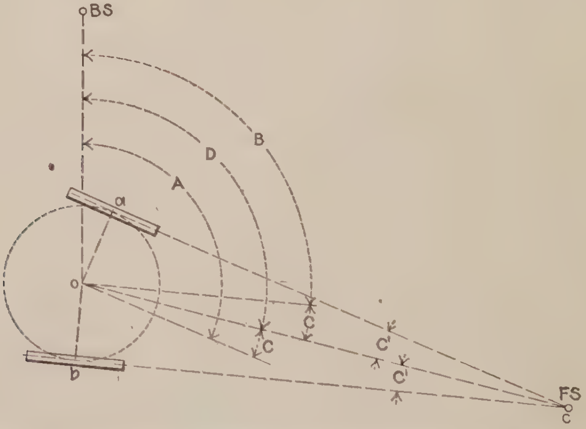

FIG. 110.—Elimination of the effect of the eccentricity of a side telescope by double reading.

It is evident that if the horizontal distances *a-b* and *c-d* were equal that the angle *B* would equal *C* and the angle read would be the true one, but this condition is not likely to occur.

With the side telescope, the telescopes can be reversed; this places the eccentricity on the other side of the center. Hence if an angle is read first with the side telescope on one side and then with it on the other, the mean of the two readings will give the correct angle. Thus in Fig. 110, let the backsight be taken with the main telescope and so be unaffected by the eccentricity, let the first reading be taken on the foresight with the side telescope at *a*, call this angle, *A*, and let the second reading be taken with the side telescope at *b*, call this angle, *B*. The horizontal distance, $a\text{-}c=b\text{-}c$; the triangles *aoc* and *boc* are equal. The true angle in each case is *D*, and in the two cases, this will be expressed by $D=A-C$ and $D=B+C$ respectively, or adding these $D=\frac{A+B}{2}$, *i.e.*, *D* is the mean of the two readings. If both back- and foresight are taken with the side telescope, the mean of the two readings, one with the telescope normal and one with it reversed, will give the correct angle, as can be seen by solving for the angle in Fig. 109, when the side telescope is on the opposite side.

This principle allows the angles of a traverse to be read by repetition, giving the advantages of that system, and at the same time eliminating the effect of the eccentricity. Care should be taken to read the angle the first time with the main telescope normal and the second time with it reversed and to record both these readings. The balance of the set can then be taken, with the precaution that the same number of sights are taken with the telescope normal as are taken with it reversed. The first two readings are then averaged giving the size of the angle and this multiplied by the total number of readings should give the last angle as recorded. This check should be made in the field before shifting the instrument; in the office a further check should be made by calculating the angle of eccentricity, correcting the first reading and comparing this corrected angle with the mean one.

In prolonging a line down a steep slope from a station in that slope, it is often convenient to put the prism eye piece on the main telescope and use it for the upward sight, and to use the side telescope for the downward one. This saves shifting the prism on the different sights. Sometimes it is convenient for other reasons, to take one sight with the main telescope and the other with the side telescope. This does not affect the results in a set of readings provided an equal number are taken with the side telescope on each side. Care must be taken that the side telescope is not changed from one side to the other while the vernier is unclamped or an error of 180° will be introduced into the angle.

It is well in making an angle reading by repetition under these difficult conditions to read and record the angle every time one is turned off, then in case of error the faulty one can be located and either be discarded from the average, or be repeated as seems best. The sights should also be taken in pairs so that the reading at the end of any pair will be a multiple of the true angle.

Measuring the Vertical Angles with the Side Telescope.—The side telescope being in the same radial plane as the main telescope, the vertical circle will give the true inclination when the auxiliary is pointed on the target.

The distance is measured from the center of the side telescope to the target and this, multiplied by the sine and cosine of the vertical angle gives the vertical distance between the instrument and target, and the horizontal distance *a-c*, see Fig. 110. This is not the exact horizontal distance between stations; it is in error by the difference between *a-c* and *o-c*. This error will be very small and may be neglected except when the horizontal distance *o-c* is very short. The effect of using the distance *a-c*, for the distance *o-c*, can be calculated for a given instrument and the distance can be determined, below which a perceptible error will result from measuring the distance on the line *a-c*.

Taking Details with the Side Telescope.—The side telescope is not convenient for taking radiating sights as the angles all have to be corrected before they can be plotted. It will not be difficult, however, to make a table showing the effect of the eccentricity on the angle at different distances, and to apply this correction to the angle in the notes before plotting.

INTERCHANGEABLE AUXILIARY TELESCOPES

It has been shown that the top telescope gives the horizontal angles and that the side telescope gives the vertical angles in their proper relation, but that each has disadvantages for the other work. The interchangeable auxiliary telescope was devised to be used as a top telescope for taking the horizontal angles and as a side telescope for measuring the vertical angles.

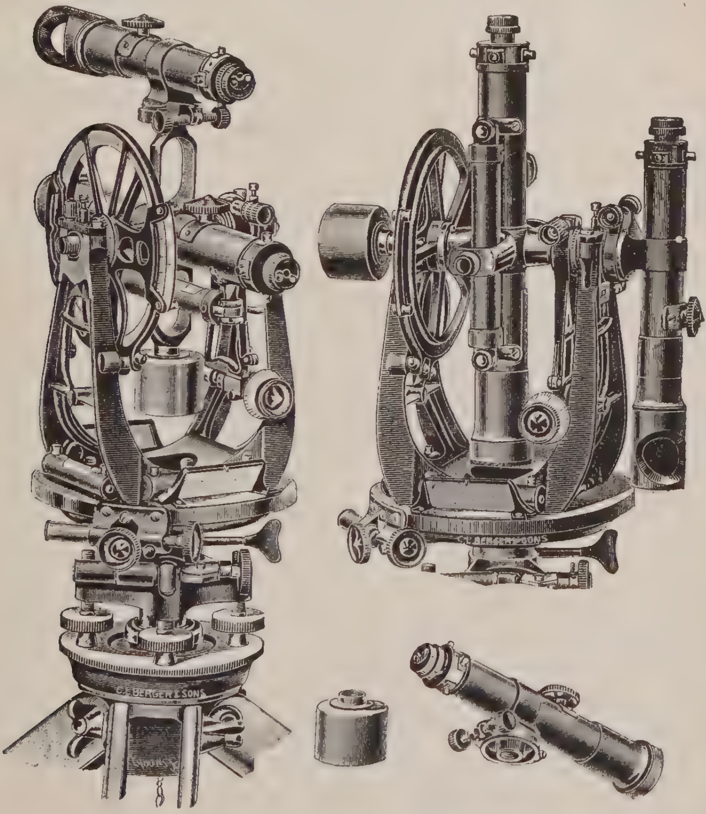

Fig. 111.—Interchangeable auxiliary telescope. Made by C. L. Berger & Sons, Boston, Mass.

The arrangement is shown in Fig. 111[1]. A skeleton standard is made in one piece with the horizontal axis, and one of its ends is threaded for attaching the top telescope and the other for the counterweight. The two ends of the horizontal axis are finished in a similar manner. The telescope is made so that it can be screwed on to one end of either the standard or the horizontal axis and the weight is made so that it will screw on the opposite end and balance the telescope. After screwing the hub of the auxiliary to the instrument, the auxiliary can be rotated slightly by means of the two opposing tangent screws, in order to adjust it into line with the main telescope, or if it is desired to set the auxiliary at an angle with the main telescope, it can be rotated about its hub by loosening the capstan headed screw on the opposite side of the hub from the tangent screws.

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[1] This device was invented by Dunbar D. Scott, in 1896, and described in *Trans. A. I. M. E.*, Vol. XVXIII, p. 739, and Vol. XXIX, p. 1004. The figures

In use, the auxiliary is attached to the end of the standard to make a top telescope while the horizontal angle is read, and then it is removed and attached to the horizontal axis while the vertical angle is read. The distance would be taped while the auxiliary is at the side. If there are any steep radiating sights to be measured, they are taken while the telescope is on top, and they can be reduced to the horizontal by using the vertical angle as read when the sight is taken, without paying any attention to the eccentricity of the top telescope, provided it is approximately parallel with the main telescope.

Adjustments.—This interchangeable arrangement of the auxiliary telescope simplifies the adjustments and does away with the necessity of getting the auxiliary line of sight parallel to the main line, provided it is in the same plane.

1. *The cross-wires* are brought into the center of the auxiliary telescope by placing it in improvised wooden Y's, pointing it on a distant object, and adjusting the wires if necessary, so that they will continue to point on the object while the telescope is rotated in the Y's.

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here show the arrangement made by C. L. Berger & Sons, Boston, Mass. Similar arrangements are made by Wm. Ainsworth & Sons, Denver, Colo., by F. E. Brandis Sons & Co., Brooklyn, N. Y., and by P. & R. Wittstock, Berlin, Germany.

2. *The vertical cross-wire of the auxiliary*, when it is on top, is made vertical by pointing both the telescopes on a distant point, moving the telescopes about the horizontal axis and adjusting the vertical wire of the auxiliary so that it will stay on the point, as the telescope is moved up and down.

3. *The line of sight of the auxiliary*, when it is on top, is brought into the same vertical plane as the main line by setting the main telescope on a distant object and bringing the auxiliary to bear on the same point by means of the tangent screws on its hub, or if the point is close, the main telescope is set on the point and rotated about its horizontal axis a little so as to bring the point into the field of the auxiliary. With the telescope at the side, the main telescope is pointed on a distant object and the auxiliary is brought on to the same object by means of the tangent screws on its hub, or if the object is close, the instrument is rotated about its vertical axis after the main telescope has been set on the point so as to bring the point into the field of the auxiliary.

The last adjustment is made each time the auxiliary is attached to the instrument and is so simple that it can be made underground. The point sighted at for the adjustment should be as far away as possible.

No attempt is made to set the auxiliary parallel to the main line of sight as this adjustment does not affect the horizontal angles when the auxiliary is on top or the vertical angles when the auxiliary is at the side.

TRANSITS WITH ECCENTRIC STANDARDS

Several attempts have been made to build transits with inclined standards so that the horizontal axis will be beyond the edge of the plates, thus allowing steep sights to be taken with the main telescope. With these transits, the horizontal angle is correct as read from the plates, the distance is measured from the center of the horizontal axis to the target, and the vertical angle is read on this same line, as is shown in Fig. 112; then the taped distance multiplied by the sine of the vertical angle will give the correct difference in height between the instrument and the target as usual, and the horizontal distance found by multiplying the taped distance by the cosine of the angle, will be the distance

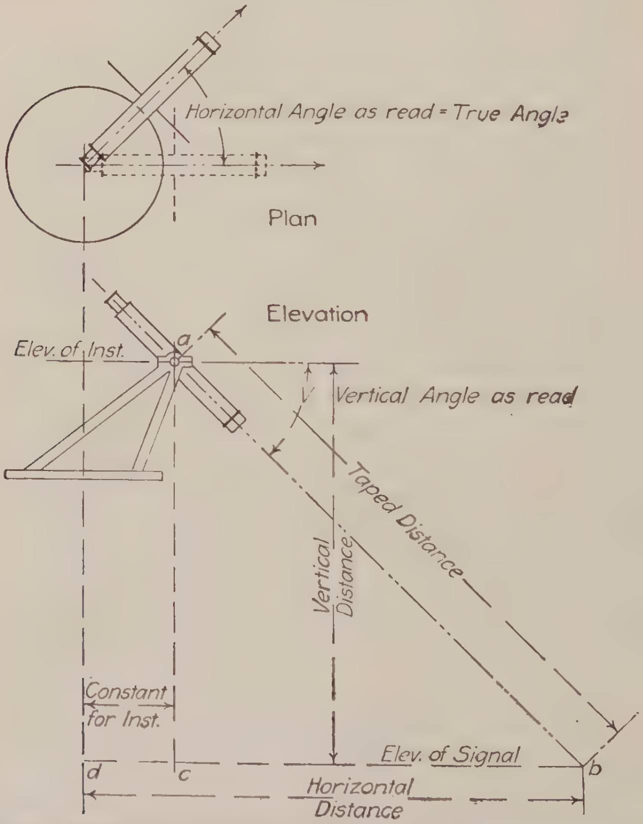

FIG. 112.—Effect of eccentric standards on the measurement of angles. Horizontal distance, $d\text{-}b = d\text{-}c + c\text{-}b$ and $c\text{-}b = a\text{-}b \times \cos V$.

Vertical distance, $a\text{-}c = a\text{-}b \sin V$.

from the axis to the target, and must be increased by the eccentricity of the horizontal axis, as shown in the figure.

A transit of this type, Fig. 113, seems to overcome the difficulties due to eccentricity that occur with the use of auxiliary eccentric telescopes. It may be more awkward to handle than the usual type of transit for regular work, but for mines with many steep connections, it would be a valuable addition to the equipment. An instrument on this principle, made by A. Lietz Co., San Francisco, from a design by C. S. Batterman, superintendent for the Butte & Montana Co, Butte, Mont., was used for an extensive new survey of mines on a vein dipping from 75° to 85°.

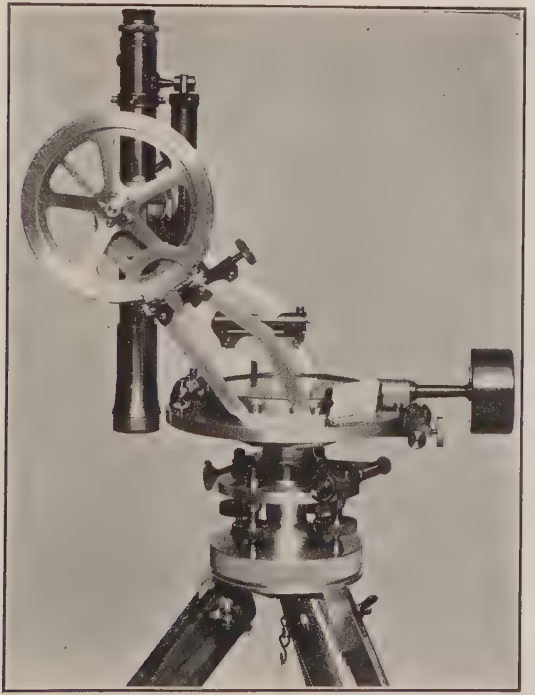

Fig. 113.—Transit with eccentric standards. Made by Young & Sons, Philadelphia, Pa.

Several attempts have been made to arrange the instrument so that the horizontal axis can be shifted from the central to an eccentric position to suit the work on hand. In one case, the regular standards were hinged but it was not successful as it lacked rigidity. In another pattern, the standards are attached to a base which can be slid across the horizontal plate by means of a screw so as to move the telescope from a central to an eccentric position; this is shown in Fig. 114. In still another case, the standards are provided with two sets of bearings, one concentric and one eccentric, so that the telescope with its horizontal axis and vertical arc can be lifted out of one set by releasing the caps over the bearings, and be placed in the other set, according to the work to be done; this arrangement is shown in Fig. 115.

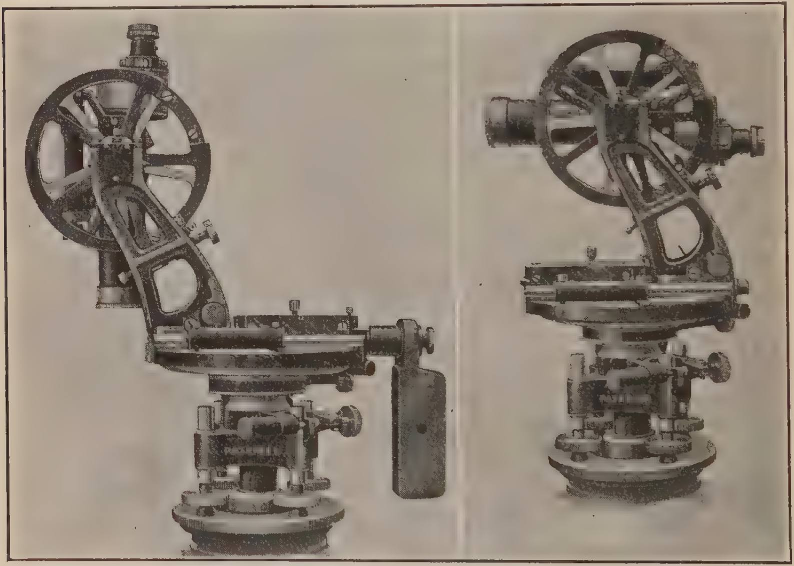

Fig. 114.—Transit with shifting standards. Made by Paul Weiss, Denver, Colo.

The last two types are expensive instruments, are heavy, and expose important parts to dirt in whichever position they are used.

Instruments with eccentric telescopes on the side are used in Europe for steep sighting. They contain the eccentric features of the auxiliary side telescope, but are more rigid. One pattern of these instruments is shown in Fig. 116 together with the eccentric targets which are constructed so that the distance from the center equals the eccentricity. Their use saves any correction

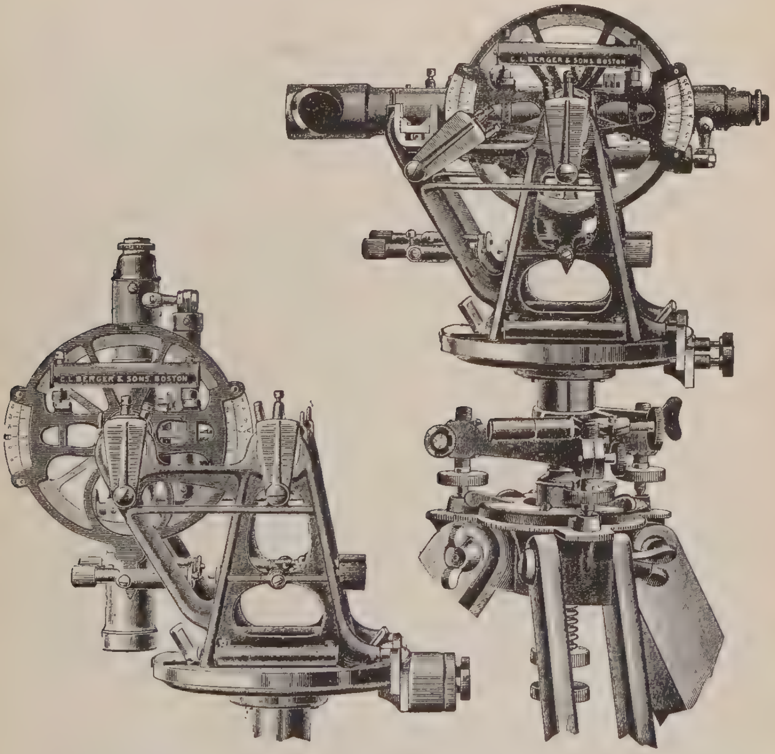
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FIG. 115.—Transit with duplex standards. Made by C. L. Berger & Sons, Boston, Mass.

of the angle as read, and as the targets are double the telescope can be used on either side. In setting up the targets, the assistant places them normal to the line of sight by pointing the sight tube on a light held at the transit.

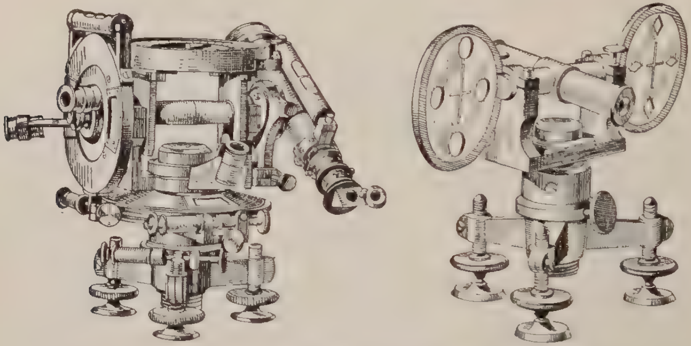

FIG. 116.—Instrument with eccentric side telescope. Made by F. W. Breithaupt & Son, Cassel, Germany.

PRISMATIC TELESCOPES

It has been proposed to attach a prism to the objective of a transit so as to bend the line of sight of the main telescope downward at right angles and allow a sight to be taken at an angle that is 90° greater than that at which the telescope is inclined. This cannot be used with an ordinary telescope as the adjustment of the prism would be deranged by the movements of the objective during the focusing.

An instrument having a telescope with a fixed objective and an interior focusing mechanism, is shown in Fig. 117. This construction secures accurate results from the use of the objective prism. The instrument also has a hollow horizontal axis with a secondary objective at its outer end to which the prism can be attached and when the secondary objective is in use, a small prism is moved into the axis of the telescope, by a screw at the opposite end of the axis, so that the rays entering the secondary objective are bent into the eye piece. This interior construction is shown in Fig. 118.

The prism is attached to either objective by means of a clamping band and can then be rotated about the axis of the telescope into any position, be clamped and finally be adjusted by a tangent screw.

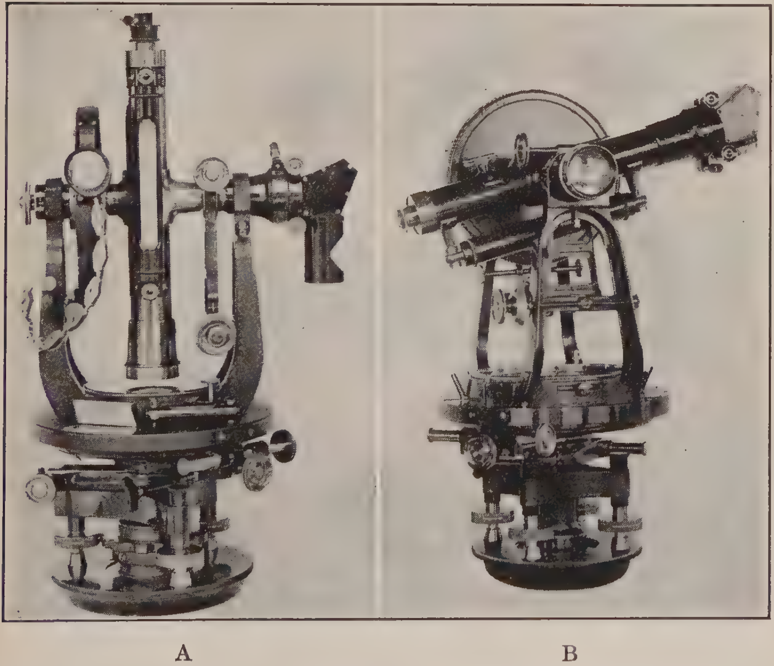

FIG. 117.—Prismatic mining transit. *A*, equipped to measure vertical angles. *B*, equipped to transfer alignment. Made by Bausch & Lomb Optical Co., Rochester, N. Y.

In preparing to transfer alignment or to read horizontal angles, the horizontal axis of the transit is accurately leveled; the main telescope is pointed on a distant object as far below the horizontal as possible, with the vertical spindles clamped; the objective prism is carefully attached, the telescope is rotated about 90°

upward and the objective prism is rotated about its axis until the same object is again bisected by the vertical wire. The lines of sight through the prism will now be in a vertical plane, whatever may be the vertical angle of the telescope, and the horizontal angles read on the plates will be the true ones.

In preparing to measure vertical angles, the instrument is accurately leveled, the prism is attached to the secondary objective at the end of the horizontal axis, the main telescope is pointed on a distant object, the interior prism is moved into place and the objective prism is rotated about its axis until the object is again cut by the horizontal wire. The line of sight through the secondary objective is now in the plane passing through the horizontal axis and the main telescope, and the vertical angles as read on the vertical circle are the true ones.

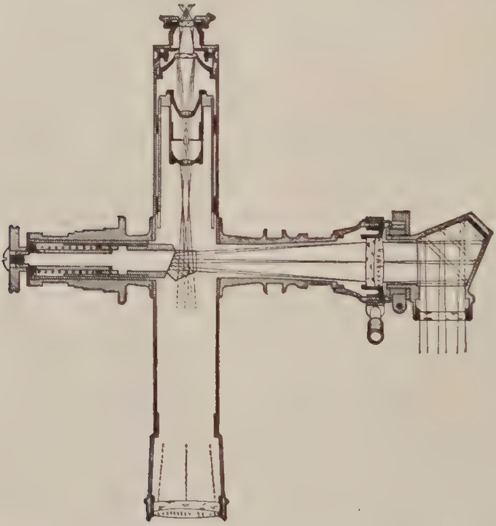

FIG. 118.—Diagram of prismatic telescope, used on transit shown in Fig. 117.

The interchangeable feature allows the prism to be used on whichever objective is best suited for the work to be done. This simplifies the adjustment by limiting it to that necessary for one position, and permitting it to be made wherever an observation is to be taken.

If the object sighted on in making the adjustment of the prism is near, it may be necessary to rotate the telescope more or less than 90° about its horizontal axis in adjusting for alignment or to slightly shift the instrument about its vertical spindle in adjusting for vertical angles, in order to see the object the second time when viewed through the prism, but this will not affect the accuracy of the adjustment.

OTHER DEVICES FOR TAKING STEEP SIGHTS

Tilting the Transit.—When a steep sight is to be taken and the standard transit is the only instrument available, a line may be transferred to underground points by tilting the whole transit, so that the steep line of sight will clear the plates, Fig. 119. This scheme was used to transfer a line down a shaft 190 ft. deep.[1] The two front legs of the tripod were shortened and the rear leg was clamped to a 300-pound casting.

In using this method, the horizontal axis must be made exactly horizontal, which may be done with the aid of a stride level placed on it. The setting can be checked by pointing the telescope at a vertical line on an adjacent building, depressing the telescope and watching whether the vertical wire follows or travels parallel to the plumb-line throughout its length. If it departs from the plumb-line, the axis must be releveled and the test repeated.

When the axis is level and the instrument is in a convenient position to transfer a line down the shaft, two points are set on the surface by the transit, and then two other points are set in the mine by depressing the telescope. These surface and underground points are in the same vertical plane and by connecting each with their respective surveys, the underground survey is oriented. The position of the transit must be determined by locating the intersection of the horizontal axis and the line of sight, when the instrument is in the inclined position, with respect to the surface survey, in order to be able to determine the coordinates of the underground station with respect to the surface origin.

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[1] "Carrying the Surface Meridian down a Vertical Shaft," by George C. McFarlan, *Eng. and Min. Jour.*, May 16, 1903.

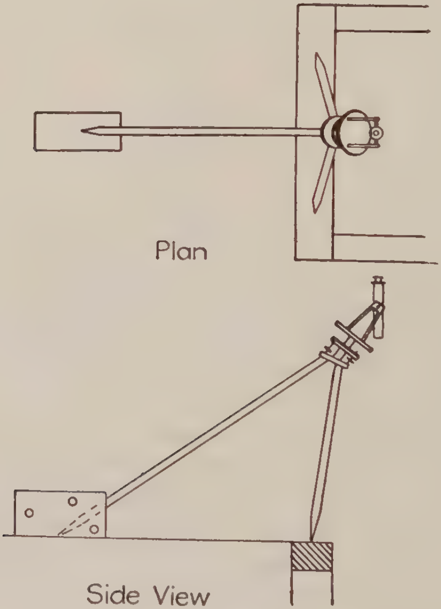

Fig. 119.—Transit tilted for a steep sight.

In setting the points in the mine, illuminated holes are desirable as signals. Spads, driven into the timbers horizontally, have been used and have been illuminated by the light from an acetylene lamp being reflected vertically upward by a mirror through a piece of ground glass held under the spad.

It is evident that the transit could be attached to a plank in an inclined position instead of tilting the tripod.

If a stride level is not available, the axis of the transit may be made approximately level by means of the plate bubble which is parallel to the axis and one pair of the leveling screws; or by turning the transit 90°, as read on the plates, to one side of the plane to be projected, bringing the vertical arc to zero and leveling the instrument with the long bubble, then on bringing it back to its original position, the horizontal axis will be level;[1] or the telescope may be leveled, and then moved 5° each side of the plane to be projected, if the travel of the long bubble is the same on both sides, the horizontal axis will be level. The axis should be finally tested to prove that it is horizontal by sighting the telescope on a plumb-line, whatever other method of preliminary leveling has been used.

In sighting down a vertical shaft, it is best to establish two points at the bottom which are to be used as a base line for the underground survey. In carrying a line down an inclined shaft, two points may be set in a similar manner, or only one may be set and it may be occupied as a transit station with the upper point used as a backsight.

Running up an Incline.—When a line cannot be carried down an incline because the line of sight strikes the plates, it can be run up by using a prism eye piece. To do this the line must be run entirely by foresights. Thus in Fig. 120, which is a plan, the instrument is set at Sta. 1. Sta. 2 and 3 are set

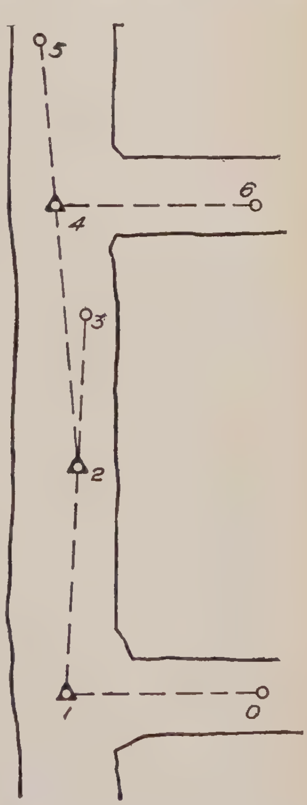

Fig. 120.—Running a line up a steep incline.

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[1] Suggested by S. W. Balch, and noted by G. A. Sutter and H. S. Munroe, *S. of M. Quart.*, May, 1882, Vol. III, p. 269.

in the same straight line and the angle 0-1-2 is read; then moving to Sta. 2, Sta. 4 and 5 are set in the same straight line and the angle 3-2-4 is read. This can be continued as far as desired. On reaching another level, the last line would be marked by a station, as Sta. 4, from which the horizontal sight could be taken, and by a point higher up the incline as Sta. 5, then the angle 5-4-6 would be read. On reaching the surface, one station would be placed where convenient for the horizontal sight and another would be located in the head frame.

ERRORS IN STEEP SIGHTS

On steeply inclined sights, the adjustment of the transit must be as perfect as possible, and advantage must be taken of every available method of eliminating errors.[1]

Errors in Sighting.—On a horizontal sight 100 ft. long an error of 0.01 ft., or about $\frac{1}{8}$ in., in the positions of the transit or of the target over their points will make an error, A, in the angle, and $\sin A = \frac{0.01}{100} = 0.0001$, hence $A = \frac{1}{3}$ *min.*, which is negligible. But if the line is inclined to 80°, the corresponding horizontal projection is only 17.365 ft. and the error, A', in the angle for the same error in setting, will be $\sin A' = \frac{0.01}{17.365} = 0.000577$ and $A' = 2$ *min.*, nearly, which is quite important. Errors are likely to occur on steep sights as the conditions are very trying, and the signals are seen with the haziness due to long sights. The effect on the angle of an error in setting or in sighting, as just shown, is the same as if it occurred on a sight equal to the horizontal projection of the line.

Error in Level of Horizontal Axis.—On a perfectly horizontal sight, an inclination of the horizontal axis will not affect the direction at all, but on a steep sight, the effect of a slight inclination of the axis is greatly exaggerated and will throw the align-

[1] This subject is discussed more fully, and largely with reference to instruments with eccentric standards in an article on "Correction for Errors," by Joseph Barrell, *Mines and Min.*, May, 1899.

ment to one side. This indicates the necessity for very careful adjustment of the collimation and horizontal axis, and for leveling the instrument with the long bubble on steep work. If there is an error of one minute in the level of the axis, the alignment will be thrown 0.03 ft. to one side for each 100 ft. of vertical distance.

Eccentricity of the Telescope.—If the line of sight of the top telescope, or of the main one with eccentric standards, is one side of the center of the instrument, the horizontal angle will be affected on the same principle as was discussed for the side telescope. This does no harm on surface surveys as its effect is eliminated on accurate work by repetition when half of the readings of the angle are taken with the telescope reversed, but on steep work the mechanical conditions prevent repetition with the telescope reversed. Thus if the line was $\frac{1}{16}$ in. to one side of the center, which approximately equals 0.005 ft., then on a 100-foot sight, the error, A, in the horizontal angle will be only $\sin A = \frac{0.005}{100} = 0.00005$ or $A = 10$ sec., but on a steep sight of 80°, the 100-foot sight reduces to a horizontal distance of 17.365 ft. and the error becomes nearly 1 min. In some cases, and with some instruments this enters on both the backsight and foresight and so is doubled, and in other cases it is cumulative.

APPLICATION OF STEEP SIGHTS

Vertical Shafts.—The survey alignment was carried down the Riverside and Home shafts at *Leavenworth, Kansas*, by means of sights with a side telescope, in order to determine the direction for driving a connection between the two mines. The shafts were each about 720 ft. deep and were but 10 ft. wide, so that the base established at the bottom was less than 10 ft. long.[1]

The horizontal axis was adjusted so that the main telescope would travel along overhead and vertical wires, as described on page 172. A second overhead wire was stretched parallel to the first and at a distance from it equal to the eccentricity of the side telescope and the latter was adjusted to follow this second wire when the main telescope was under the first wire. There were two landings about 20 ft. apart at the top of each shaft, the survey line to be transferred, was brought across each shaft at the lower landing and marked by points on the timbers on each side. The transit was clamped to a timber across the shaft at the upper level so as to be over the center of the shaft, then the timber was shifted, until the side telescope was in line with the two points set about 20 ft. below, and then two points were set in the same vertical plane at the bottom of the shaft. This arrangement of the base to be transferred reduced the effect of misadjustment of the instrument, thus if the horizontal axis was not level the line at the bottom would be parallel to the top line although a little to one side.

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[1] Abstract from "Survey of Underground Connection at Leavenworth, Kansas," by Edwin A. Sperry, *Trans. A. I. M. E.*, Feb., 1894, Vol. XXIV, p. 25.

For a target at the bottom, two straight boards were cleated together with a slit $\frac{1}{16}$ in. wide between them, but the light flared through this slit and it was unsatisfactory. A large hole was then cut in the boards at each end and an iron plate with an X cut out of it, was placed over each hole. The X was set diagonally to the line through the center slit. The light from open lamps also flared when held under the X openings, but that from a bull's-eye lantern when reflected up through these X openings was satisfactory. This method of transferring the lines down the shafts was used as the conditions interfered with the use of plumb-lines, which were tried. The shafts were about 5020 ft. apart and the length of the connection to be driven was 3251 ft., half of which was driven from each end. When the headings met there was a lateral error of nearly 3 ft., and the lines were out of parallel by $2\frac{1}{2}$ min., and the distance was 0.16 ft. more than calculated.

In the survey for the *Severn River Tunnel,*[1] a large transit was set over each shaft, on the center line of the tunnel, and the line was transferred down the shaft to a horizontal wire at the bottom of which about 14 ft. was visible.

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[1] Abstract in *S. of M. Quart.*, May, 1882, from *Engineering*, London, Jan. 20, 1882.

The headings having been driven a short distance a fine wire, 300 ft. long, was placed in the V-threads of horizontal screws, and stretched by weights. Then by turning the screws, the position of the whole wire was shifted and gradually brought into line. It was illuminated by electric lights. The headings are said to have met exactly.

CHAPTER XI

SHAFT PLUMBING

General Discussion.—It sometimes occurs that a mine is connected with the surface by both a vertical shaft and some other opening, as a tunnel, an incline or some working place which has broken through to the surface. In such a case the survey can be carried in through the flat or inclined opening with the transit, and a plumb-wire can be hung in the shaft and be connected with both the surface and the underground surveys, thus giving a check on the work. This check is not absolute as the angle between the last course in the mine ending at the plumb-wire and the surface course to the wire, cannot be measured, hence there is no check on the angles and there is a possibility of errors being made that will compensate and cause the position of the wire as determined by both the underground and surface survey to work out the same. Where the precaution to check each step is taken such a coincidence is unlikely, and the check is valuable. In other cases, the only openings that a mine has to the surface are vertical shafts and the orientation of the underground surveys must be determined by plumb-wires hung in them.

Two cases of mines entered solely by vertical shafts may occur: First, where there are two or more shafts, one wire is hung in each, the top end of each wire is located by the surface survey, a survey is run in the mine connecting the lower end of the wires, and from the known location of the wires, the underground survey is oriented. Second, where there is only one shaft, two wires are hung in that shaft and the orientation depends on the base line formed by the two wires.

Hanging the Wires.—Before commencing work in or about a vertical shaft, the top should be covered by a strong plank floor to prevent anything from being dropped down and injuring the survey party working in the shaft, and also as a safeguard to prevent any of the party at the top from falling down it. With the knowledge that the shaft is closed, neither survey party is worried by thoughts of its own personal safety. The covering also serves to check the air currents in the shaft and so may aid in keeping the plumb-wires steady. A hole is cut in the platform several inches in diameter through which the wire is hung. If part of the shaft has been left open for hoisting, it should be fenced off. At the bottom, the portion of the shaft in which wires are hung should have a platform on which the surveyors can stand without fear of falling further down the shaft or into the sump.

The wires used for shaft plumbing should be as fine as possible so as to offer the minimum surface to air currents or to the spatter of water falling down the shaft, which might deflect them, and still they must be strong enough to support heavy bobs capable of drawing them taut and straight. Piano wire is often recommended, but crucible steel wire, like that used for cast crucible or plow steel ropes, is nearly as strong and much cheaper than piano wire, as no attempt is made, in its manufacture, to secure the perfect uniformity needed for music wire. Wire that is 0.03 in. in diameter has an area of 0.0007 sq. in. and if made of crucible steel wire having a tensile strength of 200,000 lb. per square inch, it will have a breaking strength of 140 lb. and can be safely used for any bob weighing less than 50 lb.

The wire is wound on a reel, which is provided with a brake for use in lowering the wire, and some device, like a ratchet, to hold it in any position. The reel is usually bolted to some convenient framework at one side of the compartment in which the plumbing is to be done, and from there the wire is led to a guide attached to a timber directly over the shaft. The guide is often only a notch in an iron plate. The reel and guide must be so placed as to be free from vibrations. Fig. 121 shows the German shaft plumbing apparatus, designed by Prof. Dr. M. Schmidt. The middle device may be used as a guide to hold the wire at the top but it is intended for centering the wire at the bottom as explained on page 213. The plumbing apparatus is all simple in principle and can be made in any shop by varying the design to suit the materials available.

A clamp is often attached to the wire above the guide so as to support the wire and prevent more of it from passing down the shaft in case the reel should slip. If this happens, it might cause the bob to touch at the bottom and so prevent it from hanging true. The jaws of the clamp must be so shaped that they will not cut the wire or even dent it as steel wire of high tensile strength is very brittle and may snap where marked.

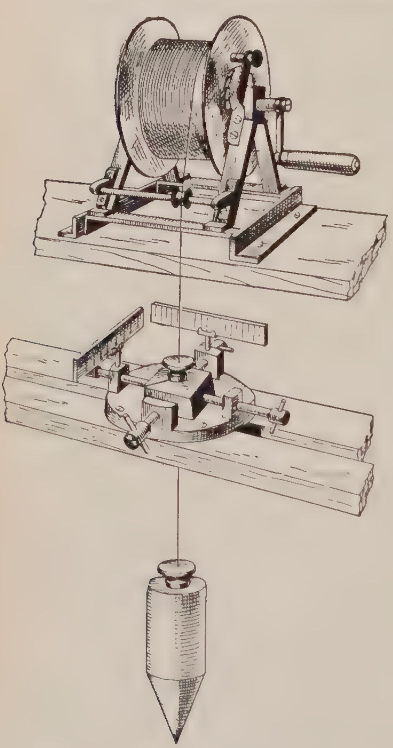

Fig. 121.—Reel and centering device for plumbing wires. Made by F. W. Breithaupt & Son, Cassel, Germany.

The wire is lowered in the center of the shaft so as not to touch anything, by means of a weight of say 5 lb. When this reaches the bottom an additional weight is added to give the desired tension, or the light weight is exchanged for a heavy one, care being taken that the hold on the wire is not lost, in making the exchange.

In general, the weights required are roughly proportional to the depth of the shaft, in order to keep the wires taut and to resist the effect of falling water and air currents which tend to vibrate them. A 5-pound weight may be enough in a shallow winze, a 10-pound one may do for a few hundred feet, and a 50-pound one may be needed in a deep shaft. No exact rule can be given as the external forces that cause trouble are seldom the same.

The plumb-wire with its weight acts like a long pendulum and to check its oscillation as much as possible, the weight is hung in a tub of some liquid, water may be used but more resistance to oscillation is offered by thick oil or molasses. The weight used may be of any shape or material heavier than the liquid, but it is desirable that it should have a large surface so as to increase the area resisting oscillation, and it should be of high specific gravity so as not to be materially affected by the buoyancy of the liquid. For these reasons a lead or iron prism having the shape of a cross or a star in cross-section is the ideal kind of a weight.

The tub should be covered with boards except for an opening through which the wire can swing without touching. This is to keep the water that may be dropping down the shaft from falling in the tub and disturbing the quiet of the liquid. As oil is less ruffled by water spattering into it than other liquids, it is usual to add a top layer of heavy cheap oil when water or molasses is used for the main liquid. The tub should stand on a plank that is not subject to jars, due either to men walking about or to machinery, that would ruffle the liquid in them.

When the heavy weight is attached to the wire, it will stretch considerably, especially if the weight is near the elastic limit of the wire, and this stretching may continue for some time, hence it may be necessary to raise the wire several times and constant watch must be kept to see that the weight does not touch the bottom of the tub. If the mine is provided with a telephone, it can be used in communicating between the top and the bottom but if there is none, it will be necessary to arrange signals whereby the man at the bottom may direct those at the top to raise or lower the bob or to stop. These signals may be the same as those used in hoisting and may be sent by the apparatus usually employed for the hoisting signals, or by taps on some of the pipes in the shaft. It is well to have some means by which the man at the top can acknowledge the signals, as by repeating them. In addition to the up and down signals, others are needed to express the directions N., E., S., and W., and to notify each other when "Ready," "Not ready or wait" and "Correct."

The wires used in plumbing shafts 4250 ft. deep at the Tamarack Mine, Calumet, Mich., in 1901–2, were No. 24 piano wire. They were lowered from drums attached to a small hoisting engine, and were prevented from catching in the timbers by a wooden balloon attached to their ends. These balloons were 10 ft. long and $2\frac{1}{2}$ ft. in diameter at the center and weighed 20 lb. each. A lantern was swung in the center of each. At the bottom an 8-pound bob was hung on the wire in place of the balloon, until they were adjusted in position, then the final weight of 50 lb. was added. This caused the wires to stretch 15 ft. After shortening, the weights were immersed in cylinder oil which lifted them 25 in., due to its buoyancy.[1]

After hanging a wire, it must be examined its entire length to see that it is free and does not touch any obstructions. In a shallow shaft, a light can be passed around the wire at the bottom and if it remains in sight, as viewed by the surface party, during the entire circuit, it would show that there was nothing in the way. In a deep shaft, the light alone cannot be depended on but the wire must be examined throughout its entire length by men traveling down the shaft, either climbing from timber to timber or by going down the ladders or in the cage and at intervals climbing through to the compartment where the wire is hanging. Still another plan that has been recommended is to move the wire a definite distance at the surface and see that it moves a like amount at the bottom. After the wire is reasonably still it is moved, say 1 in. north, then at intervals of five minutes, it is moved so as to occupy the four corners of a square, Fig. 122, and is returned to the original point as

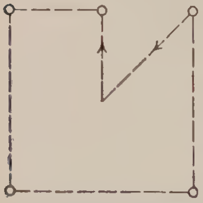

FIG. 122.—Method of shifting a wire.

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[1] *Eng. News*, Oct. 31, 1901.

shown by the dotted lines. If it moves a like amount at the bottom, it is safe to assume that the wire does not touch anything.

Additional notes on the hanging of plumbing wires are given in Chapter XII in discussing shaft plumbing for tunnel work where other conditions occur.

Locating the Wire at the Surface.—The location of the wire with respect to the surface survey is found by sighting on it from a nearby transit station, reading the horizontal angle between the backsight on the previous station and the foresight on the wire by the method used for the angle reading of the surface traverse; and by measuring the distance from the transit to the wire. The best practice is to sight directly on the wire, at a point a little below the guide, which should be placed high enough above the collar of the shaft so that the wire can be seen from the transit and still leave no great length of wire exposed to air currents, that might cause it to vibrate.

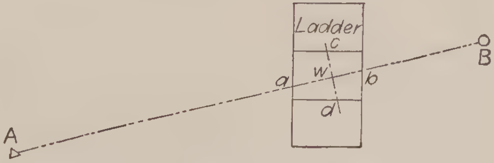

Fig. 123.—Locating a wire at surface.

As the best position for the wire in the shaft cannot be determined before it is hung, the best position for the transit for viewing it is also uncertain, especially in a cramped shaft house, so the transit point may not be set until after the wire is in place. Then instead of reading the angle to the wire, the line from the transit to the wire is prolonged and a special hub is set on this line on the opposite side of the shaft, see Fig. 123. This observation can be repeated several times, with the telescope normal and reversed, and the mean position finally marked on the further hub. The distance, *A* to *W*, from the transit to the wire and the distance, *W* to *B*, from the wire to the further hub, and the distance, *A* to *B*, from the transit to the hub, may be measured and checked. The sum of the two short lines should equal the total distance. This locates the wire with respect to the points *A* and *B*, with great accuracy, and later the survey may be brought up and connected to the line *A-B*.

As an additional record of the position of the wire, points *a* and *b*, may be marked by nails driven into the shaft timbers on the line *A-B*, and also a fine wire may be stretched across the shaft approximately at right angles to *A-B* and the points *c* and *d* marked with nails. The distances from the wire to each of these nails can also be measured. Having the points, *a*, *b*, *c* and *d*, the plumb-wire can be reset in its original position by stretching fine wires between these points if it is desired to relocate it for any purpose or to make sure that it has not been moved.

Sighting on the Wire in the Mine.—After the wire is in place, the transit is set up at the bottom at a convenient point for viewing the wire and the position of the wire is determined by line and distance. Practically the same general method is used as was described for the surface, the line from the transit to the wire is prolonged and marked by a permanent point on the opposite side of the shaft, the distances to the wire from both points are measured and later, this line through the two points is connected to the regular mine survey.

At the surface, the wire hangs practically still and it is easy to sight at it, but at the bottom, the weight and the plumb-wire act as a long pendulum and swing back and forth. The swings are so slow that they cannot be bisected with the eye and the vertical wire of the transit set on the bisection, as can be done with an ordinary bob that swings a little. The bisection must be found as the mean of a number of observations.

In order to find the mean position of the wire, a scale is set up behind the wire at *A*, see Fig. 124, and normal to the line from the transit. If this is illuminated, the wire will appear against it as a black line, the end position of the swings can be read and recorded, and the mean position can be figured from them. This mean position is then marked on the scale, a common pin stuck in the top of the scale makes a good marker, and the line from the transit to this mark is prolonged and permanently marked at *D*. The line from the transit to *D* is used as the required line through the wire, and forms part of the underground traverse.

The scales that mark the positions of the wire must be mounted on planks that are attached to the solid timbers of the shaft so as to be free from vibrations caused by the attendants walking on the platform in the shaft.

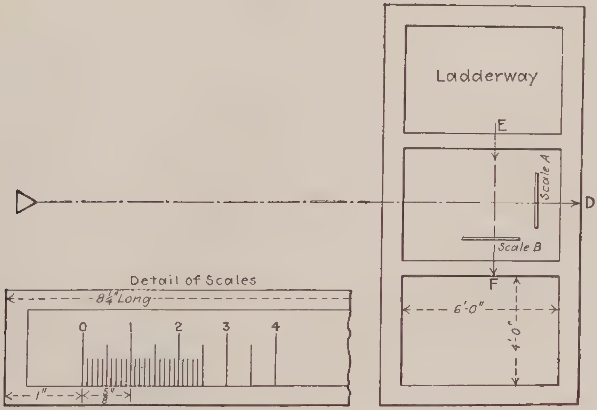

Fig. 124.—Determining the position of a wire in the mine.

The wire does not oscillate uniformly like a clock pendulum, but wobbles about in an irregular path as it is deflected by air currents or by drops of water falling against it, hence its mean position parallel to the line through the transit must be determined in order to get the distance from the transit to the wire. This can be done by means of a second scale set at *B*, parallel to the line through the transit, and the position of the wire in this direction can be observed through a second telescope set at *E*, at right angle to the main one. If a second telescope is not available, a slit like a compass sight may be used instead, or the mean position of the wire may be found by the shadow method, for which a lamp with a steady flame as an acetylene or bull's eye lantern is set at one side of the shaft, as at E, so that the shadow of the wire is thrown on the scale at B, on the opposite side. As the wire swings to and fro the extreme positions of the shadow are noted and from these the mean position of the shadow is found. The mean position of the wire is on a line joining the mean point on the scale with the telescope, slit or lamp, depending on which was used. This line can be marked by a fine wire stretched across the shaft and held by nails driven in the timbers at E and F. The distances from the transit and from the point D to this horizontal wire will then be measured.

In using the shadow method of locating the wires, it is not necessary that the scale should be graduated. The shadow can be followed with a pencil and a mark made at each end of its travel. These can be transferred to a slip of paper which can be folded giving the central point of that swing; a number of such center points can be found and the mean used as the true center.[1]

The scales can be laid out on white drawing paper, glued or shellaced to boards, and coated with shellac or varnish to make them waterproof. They should be about 8 in. long and the center 6 in. graduated. The divisions may be about $\frac{1}{16}$ in. apart and numbered in groups of ten for convenience in reading, as shown in the figure. If the graduations are all numbered in one direction as shown, the arithmetical mean of any two successive readings will give a center for that pair of swings. As the wire receives new impulses at irregular intervals, the center of each pair of swings must be found and then the average of these various positions will give the mean position of the wire. Thus in Fig. 125, let the zigzag line represent the amplitude of successive swings of the bob. Then the center position of each double swing is shown by the spot on the line and the mean position found by averaging all these points is given by the expression: *Mean Position* = (*First Swing* + *Last Swing* + *Twice the sum of all Intermediate Swings*) *divided by* (*Twice the number of swings less*

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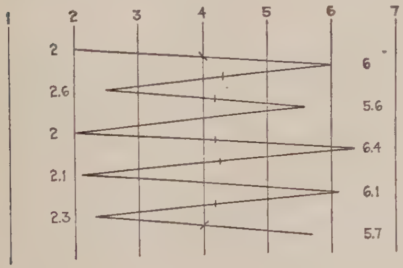
[1] L. F. J. Wrinkle, *Eng. and Min. Jour.*, Jan. 28, 1893, Vol. LV, p. 81.

two). This is shown in column *A* in the figure where the mean position is found to be at 4.11. As the swings do not follow any law, it is probable that a simple average of the amplitude of an even number of swings will give a mean position that is practically correct and is more quickly figured. Thus in column *B* the average position is at 4.08, which is not materially different from the position found by the first method.

Others advocate the taking of an odd number of readings, as is done in finding the zero point of a balance.[1] This assumes that the weight vibrates under the influence of gravity and is retarded only by friction, but the wire is not a perfect pendulum, as it receives irregular impulses, and so the law of balances does not apply.



Column A Values weighted	Column B Average
2.6	2.
2.	2.6
2.1	2.
2.3	2.1
6.	2.3
5.6	6.
6.4	5.6
6.1	6.4
33.1	6.1
×2	5.7
66.2	10)40.8
2.	4.08
5.7	
18)73.9	
4.11	

FIG. 125.—Averaging the swings of a plumbing wire.

Whatever system of averaging is used, several sets of observations should be made at intervals of a few minutes, and all the results averaged, unless some one set seems to contain a violent disturbance, when it may be eliminated.

Dr. M. Schmidt devised a neat centering apparatus in 1884, see Fig. 121, having the two scales mounted at right angles on a base, the center of which is cut away to allow the wires to hang freely through it. Then having determined the mean position by the scales, a block clamping the wire is inserted in the base, and adjusted by set screws so as to bring the wire into the mean position. The transit observations are then taken on this fixed wire.[1]

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[1] F. W. McNair, *Eng. and Min. Jour.*, April 26, 1902, Vol. LXXIII, p. 578.

A diaphragm having a series of vertical lines engraved on it and inserted at the cross-wires of the transit telescope has been used by Prof. Brathuhn as a means of observing and bisecting the oscillations of the plumbing wires.[2]

During the plumbing operation it is desirable to have two transits, then the assistant and his party can be left on top with one instrument to set and determine the location of the wire and the chief and his party can go below with the other, and tie the wire to the underground traverse. Where only one instrument is obtainable, the wire must be hung and located at the surface and then the party must be sent to the bottom and permanently establish the lower position of the wire. If the wire is hung in the only hoist-way, the party may have to descend by the ladders and carry their outfit. If there are two hoist-ways, it may be possible to do the plumbing in one and use the other for raising or lowering the men.

Since the base line at the foot of the shaft is at a point where there is considerable travel, it is liable to be disturbed, and since it is in a busy part of the mine, it cannot be used at times without inconvenience to the mine operations, hence the permanent base line for the underground surveys should be transferred to a series of two or more points off of the main line of travel where it will not be injured and to which the surveyor can refer as often as he wishes.

PLUMBING WITH TWO OR MORE SHAFTS

When there are several shafts, one plumb-wire is hung in each, the wires are connected with the surface survey and with the mine survey, and the relation of the underground survey to the surface survey is determined by calculation.

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[1] D. D. Scott, *Trans. A. I. M. E.*, Vol. XXVIII, p. 711, Oct., 1898.

[2] *Trans. A. I. M. E.*, Vol. XXVIII, p. 736, Oct., 1898.

The orientation of the underground survey is complete if the wires are hung in two shafts, provided there are no errors, but if there are other shafts, they should be plumbed also and connected with the survey as a check on the other work.

The principle of orienting the mine survey by a wire down each of the vertical shafts is clearly shown by a graphic solution of the problem. If plots are made, both to the same scale, of the surface and the mine surveys, they will both have the shafts on them and one map may be placed over the other so that the shafts correspond, then the mine map is oriented with respect to the surface. The same process is performed mathematically where the orientation and coordinates of the underground survey are determined by calculations instead of by plotting.

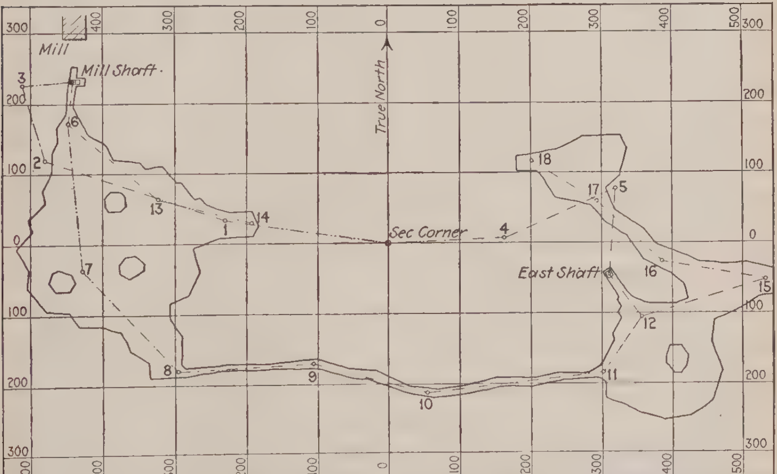

FIG. 126.—Map of a mine showing survey lines both surface and underground.

The main steps in the process of calculating the orientation of the mine survey are:

1. The bearing of the imaginary line joining the shafts is calculated from the surface survey.
2. The angle between the first course of the mine survey and the imaginary line joining the shafts is found from the mine survey.
3. The bearing of the first course of the mine survey is calculated from the bearing of the imaginary line and the angle which it makes with the first course.

The method of procedure is best shown by an example with actual figures, in which the operations are given in detail, thus, let Fig. 126 be a plan of the mine and surface showing the survey stations.

First, the surface survey is started from the section corner and run to each of the shafts. Sta. 3 and 5 are located close to the shafts, the shafts are plumbed and the wires are located from the adjacent stations. The condensed field notes of the traverse are as follows:

FIELD NOTES OF SURFACE SURVEY.—(*Condensed*)

Station	Horizontal angle	Horizontal distance
North meridian = *B. S.*		
0	278°-14¾′	232.08
1	190°-44¾′	263.83
2	234°-30′	111.03
3	281°-15½′	70.00
Mill Shaft wire = *F. S.*		
North meridian = *B. S.*		
0	87°-30′	162.50
4	158°-15′	172.79
5	298°-45′	124.63
East Shaft wire = *F. S.*		

The coordinates of the stations of the surface survey are calculated giving the results listed on the next page.

These are plotted as in Fig. 127 and the length and azimuth of the line from the Mill Shaft to the East Shaft is found as shown below the figure; giving the length as 800.96 ft. and the angle which it makes with the meridian as 69°–40′, which is equivalent to a bearing of S. 69°–40′ E., or to an azimuth of 110°–20′.

COORDINATES OF THE SURFACE SURVEY STATIONS

Station	Latitude	Departure
0	0	0
1	N 33.30	W 229.67
2	N 119.20	W 479.13
3	N 225.66	W 510.67
Mill Shaft wire.	N 232.07	W 440.96
4	N 7.09	E 162.35
5	N 78.06	E 319.89
East Shaft wire.	S 46.19	E 310.11

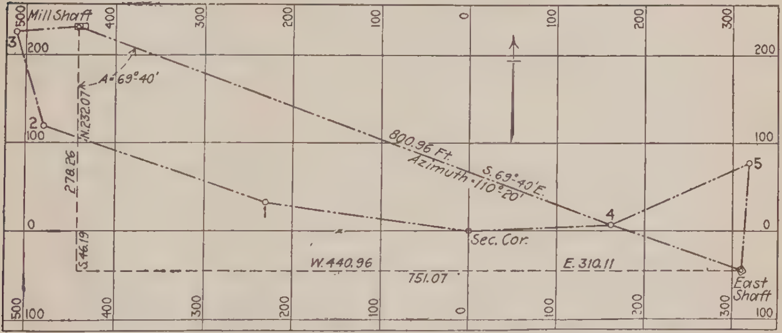

Fig. 127.—Plot of the surface survey connecting the shafts.

The length of the hypothenuse of the right-angle triangle, whose legs are (440.96+310.11) and (232.07+46.19) respectively, or the length $M.S.$ to $E.S. = \sqrt{(751.07)^2 + (278.26)^2} = 800.96$ ft., and the angle A which this hypothenuse makes with the meridian is, $\frac{Dep.}{Lat.} = \tan A$ or $\frac{751.07}{278.26} = \tan 69°$-40′, hence $A = 69°$-40′ and the bearing of the line $M. S.$ to $E. S.$ is S. 69°-40′ E., or its azimuth is 110°-20′.

Second, the mine survey is run from Sta. 6 near the Mill Shaft through the connecting drift to Sta. 12 near the East Shaft. The foot of the wire in each shaft is located and is connected with the adjacent station of the survey. The condensed field notes of this traverse are as follows:

FIELD NOTES OF MINE SURVEY.—(*Condensed*)

Station	Horizontal angle	Horizontal distance
Mill Shaft wire = *B. S.*		60.00 ft.
6	169°-29¾′	209.80
7	142°-45½′	194.46
8	129°-44¼′	189.59
9	197°-30¼′	165.00
10	158°-44¾′	249.94
11	131°-04′	95.80
12	107°-56¾′	75.00
East Shaft wire = *F. S.*		

Third, the underground survey is plotted on tracing paper by a protractor to the same scale as the surface map, as in Fig. 128, and is oriented by placing it over the surface map so that the shafts coincide. This shows that the line from the Mill Shaft wire to station No. 6 bears nearly south.

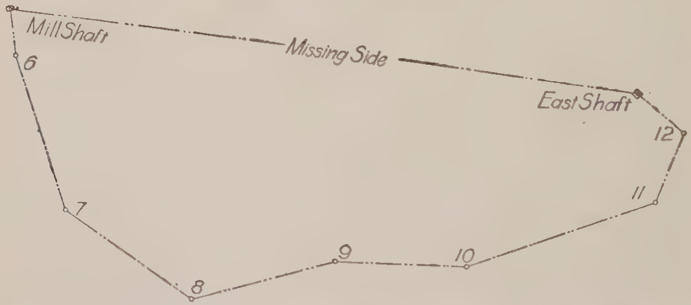

Fig. 128.—Protractor plot of the underground survey connecting the shafts.

This graphic solution, especially if the plots are made to a large scale, affords a check and a guide for the subsequent calculations.

Fourth, a preliminary calculation of the underground survey is made, using the coordinate of the Mill Shaft wire at zero and an assumed azimuth of 180° for the line *M.S.* to Sta. 6, from which calculation the missing side *M.S.* to *E.S.* is found to be 800.96 ft. long and to have an azimuth of 105°-05′, that is the angle between this line and the course, *M.S.* to Sta. 6 is 74°-55′.

The missing side between the shaft wires, being directly under the line joining the tops of the wires must have the same length and direction as that found for it by the surface survey. The lengths agree, and form a check on the accuracy of the surveys and the calculations. The angle found by the mine survey between the line connecting the shafts and the first course was 74°-55′ which applied to the azimuth of the line between shafts as found by the surface survey gives 185°-15′ as the correct azimuth of the first line of the mine survey and from this the azimuth of the other lines are calculated, thus orienting the mine survey.

The same conclusion could have been reached by noting that the azimuth of the connecting line *M.S.* to *E.S.* as determined by the trial calculation of the underground survey was 5°–15′ smaller than its azimuth as determined by the surface survey, hence this angle of 5°-15′ must be added to the azimuth of each of the courses of the mine survey to give them their true relation to the meridian. This is, in effect, a rotation of the underground survey, through 5°-15′ to the right about the *M.S.* and is similar to the shifting of the paper plots in the graphic solution.

Fifth, with the correct azimuth for the underground courses, and the known coordinates of the Mill Shaft wire, the final calculations of the mine survey are made giving the following coordinates for the underground stations referred to the surface origin and meridian:

COORDINATES OF THE MINE SURVEY STATIONS.

Station	Latitude	Departure	Elevation
Mill Shaft wire = *B.S.*	N 232.07	W 440.96	
6	N 172.32	W 446.45	827.72
7	S 36.60	W 427.25	836.16
8	S 179.97	W 295.87	850.67
9	S 170.87	W 106.46	871.23 R
10	S 212.88	E 53.10	873.78 R
11	S 184.59	E 301.43	865.35
12	S 105.69	E 355.77	865.14
East Shaft wire.	S 46.19	E 310.11	

These stations are plotted giving the map shown in Fig. 126. From these stations, the survey can be extended to other parts of the mine and, knowing the coordinates of these stations and the azimuth of the courses joining adjacent ones, the coordinates for the new stations can be calculated, thus tying them to the origin of the surveys on the surface.

The only check on the underground traverse is the comparison of the length of the missing side between the shaft wires, as found by the mine survey with the length as found by the surface survey. It is well, therefore, to run the surface and the mine traverses connecting the shaft wires as closed circuits, returning by a different route so as to make sure that no error has been made in either traverse. In the mine the return route may have to pass through the same passage as used for the first running of the line but different stations may be used thus giving different figures as the basis of the calculations.

If there are other shafts available, the survey should be extended to them, they should be plumbed and the underground survey closed on them. If the coordinates of the plumb-wires in these other shafts as found by the mine survey are the same as those found by the surface survey, the correctness of the surveys is proved.

Abstracts.—In the *Joplin, Mo., zinc-lead district*, many of the mines are worked through vertical shafts from 100 to 150 ft. deep and the hoisting is done with a bucket. In plumbing these shafts, the author used the hoisting rope as the plumbing line. The bucket was lowered to within a few inches of the bottom and the sight was taken on the rope at the surface, after which the party was lowered into the mine and prepared to take the observations at the foot of the shaft. While this was going on, the hoisting of ore was resumed. When the surveyors were ready the bucket was again stopped a few inches from the bottom, steadied by hand, a white illuminated surface was held behind the rope and a sight was taken and the distance from the transit to the rope was measured.

This apparently rough method gave good results in this case, as the bucket hung free, there being no guides, the hoisting rope was only $\frac{5}{8}$ in. in diameter, the shafts were shallow, the buckets hung very quietly, and the mines were small. The workings depending on any set of plumbings were included in an area of 500 by 200 ft.

This method of procedure is not recommended where the underground surveys are very extensive or important decisions depend on the survey, but it is given to show how work can be simplified by adapting the methods to the conditions.

PLUMBING WITH ONE SHAFT

When there is only one vertical shaft, connecting the mine with the surface, the alignment of the underground survey must be obtained from two wires hung in this shaft. The wires are set at the surface on a line whose direction is known and in the mine a line through them is prolonged and marked out, forming a base of known direction by which the underground survey is oriented.

The operation is very simple in principle and no calculations are involved, but the length of the base formed by the two wires is often short, perhaps only 4 ft., hence a small error in determining the position of the wires is greatly magnified, in extending the survey.

The general methods of hanging and of locating the wires, discussed in the first part of this chapter, are followed with some minor variation in the details. The wires must be hung so as to give the longest base possible and so that the transit can be set in the prolongation of the line through them, both on surface and in the mine; the conditions in the mine are generally the controlling ones as the obstructions on the surface can usually be moved or an opening cut for the line of sight. If the shaft has several compartments and there is a pump chamber at one side, Fig. 129, Case A, where the transit can be placed, a good base can be obtained by hanging a wire at the outer side of each hoisting compartment. If there is no chamber at the side of the shaft, the wires must both be hung in one compartment and the base is much smaller, as in Fig. 129, Case B.

In planning the work of the party, it should be noted, in Case A, that both hoisting ways are occupied by the plumb-wires and so no traveling between the top and the bottom can be done except by the ladders, and in a deep mine this will require the use of a transit at the surface and another in the mine, but in Case B, the cage can be run in one compartment without interfering with the wires. Occasionally when the conditions are like Case A, one wire can be hung in the ladder and pipe compartment thus leaving one hoist-way free for travel, but usually the ladderway is obstructed by landings at the end of each length of ladder or by timbers to support the pipe, so it is not available.

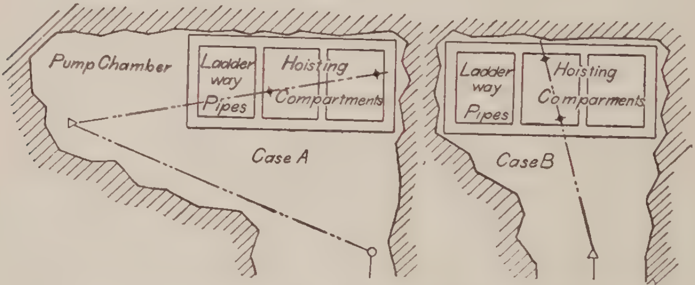

FIG. 129.—Lining-in with the wires at the foot of the shaft.

After the wires are hung so as to suit the conditions, and give the longest base, they are examined throughout their length to see that they hang free. They are then located on surface by setting the transit in line with them and transferring this line to hubs which are afterward connected to the surface system of surveys, thus establishing the direction of the base through them.

The approximate position of a transit can be found by stretching a cord tangent to the two plumb-wires and setting the transit over this line. The setting may be perfected by pointing the telescope on one wire and then shifting the transit, by moving the legs or its shifting center until the second wire is in line. In sighting at the two wires, both can be seen at once provided the transit is near enough to the wires for rays of light from the further one to pass the near wire and still strike the objective.

The hub under the transit can be set after the cord has been stretched and when the transit setting has been completed, the exact station mark can be made on it. The hub on the further side of the shaft is set and marked after the transit is in line. The distance between the wires, the distance from each wire to each hub and the distance between hubs are measured. Marks are also made on the shaft timbers on each side, so as to preserve the location of the wires and so that they could be reset if desired.

At the bottom, the mean position of both wires should be determined by some of the averaging methods previously described. Then a cord can be stretched tangent to them and a transit set over it, outside of the shaft, and shifted into exact line. The position of the transit is marked by a station and a second station mark is set beyond the wires and in line with them. The distances from each wire to each station point, the distance between the wires and the distance between the two station points is then measured.

The base thus established gives a line in the mine whose azimuth with the surface meridian is known and the coordinates of the top end of one of the wires being found on surface, and being the same at the bottom end, gives the relation of a point in the mine to the surface origin. These completely locate and orient the mine survey, when it is connected with this base.

To facilitate the lining in with two wires,[1] the near wire may be cut a few feet above the weight and three links of ordinary chain be inserted, then the far wire can be seen through some one link, no matter how much the wires twist, and the surveyor can be sure that he sees both wires.

In addition to the tests that may be applied to the wires to see that they clear everything, the measurement of the distance between the wires affords another check on their hanging true. If they do not measure the same distance apart at both top and bottom, something must be wrong.

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[1] *Col. Eng.*, Aug., 1896, and July, 1897.

When the conditions are such that the transit can be set in line with the two wires, the positions of the wires at right angles to the line through them are of the greatest importance, as these determine the direction of the base, hence the principal scales are placed normal to this line and behind each wire. If the shadow method is used, the strips receiving the shadow are placed beyond each wire and the light is placed on line and near the other wire.

Abstracts.—At one mine, with a *shaft* 390 *ft. deep,* iron bobs were deflected so that their bottoms were 7 5 mm. further apart than at the top and the line connecting them was 6 min. out of parallel with the top line. The trouble was traced to a pile of old rails in a cross heading. These lay with their ends turned toward the shaft and acted as magnets to attract the near bob. The trouble was remedied by using brass weights.[1]

At the *Tamarack mine,* near Calumet, Mich., Shaft No. 5 was plumbed in September 1901, the plumbing-wires were of No. 24 steel piano wire and 4250 ft. long as hung, and the bobs were cast iron and weighed 50 lb. each. After taking the greatest care to ensure that the wires hung free, a measurement of the distance between them at the bottom was greater than at the top.

The discrepancy caused considerable discussion, and various explanations were suggested. One was that a 16-inch and a 4-inch pipe in one end of the compartment acted as magnets and attracted the near wire which was only 7 ft. from them. This was disproved by the plumbing of Shaft No. 2 about one week later where lead weights were used, but still there was a divergence of 0.1 ft. A second suggestion was, that the rock walls at the end of the shaft being closer to one bob than to the other, drew the near bob to that wall and hence away from the other one. While there is such an attraction, the amount of deflection caused by it would be imperceptible. A third suggestion was, that the bobs were of like polarity and repelled each other. The observations made at these shafts were as follows:

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[1] Brathuhn, *Berg-und Hutten-mannische Zeitung,* 1898.

LIST OF PLUMBINGS AND DATA OBTAINED

Shaft	Date	Setting	Wire	Bob	Distance apart		Difference
					top	bottom	
No. 5, 4250-ft. wire	Sept., 1901	1st	steel	iron	16.32	16.43	0.11 div.
	....	2nd	steel	iron	17.58	17.65	0.07 div.
No. 2, 4100-ft. wire	Sept., 1901	....	steel	lead	12.60	12.70	0.10 div.
No. 5	Jan., 1902	....	bronze	....	16.709	16.850	0.141 div.
	Feb., 1902	....	bronze	....	11.944	11.962	0.018 div.

Experiments were made by the company and other engineers in Shaft No. 4 to find the cause of the divergence. This shaft was freer from magnetic materials than any of the others. Phosphor-bronze wire No. 20 B. & S. gage and lead weights were tried. They were steadied in tubs of oil and later in water. The wires from the point of support to the bottom of the weights were 4440 ft. long. The results with the different wires were:

January 1902	Wire	Bob	Medium	Distance apart in feet		Difference
				at surface	at 11th level	
3rd............	Bronze	Lead	Oil	15.089	15.061	0.028 Con.
6th............	Steel	Lead	Oil	15.089	15.074	0.015 Con.
6th............	Steel	Lead	Water	15.089	15.074	0.015 Con.
6th............	Steel	Iron	Water	15.089	15.062	0.027 Con.
9th............	Bronze	Lead	Water	14.607	14.611	0.004 Div.

These seemed to offer experimental proof that there was no magnetic repulsion between the wires, and that the attraction of the walls did not act to spread the wires for here the discrepancies, though slight, were converging ones except the last.

In January bronze wires were again hung in shaft No. 5 as near as possible in the same position as in September, and the divergence was greater than in September, see table. The effect of air currents was then reconsidered; it had been previously suggested but discarded as it was thought to be impossible for air currents to produce such uniform deflections of the wires. The top of the shaft and all side openings into it, were then closed thus causing horizontal currents of air to cease. On February 23rd, the wires were rehung and the distances at the top and bottom agreed within 0.02 ft. The convection currents which could not be entirely stopped probably accounted for the small divergence that occurred. The distance between the wires was less in February than previously, as they were hung in different compartments in order to take advantage of the quieter air.[1]

At *Leavenworth, Kan.*, attempts were made to plumb two shafts, 720 ft. deep; but the swirling air currents even when the ventilating fans were stopped, threw the water from side to side, causing it to strike against the wires and preventing the bobs from settling to such an extent that the method was abandoned. The wires were fine piano wire, the bobs weighed 5 lb. each and had slots sawed in them, in which were inserted brass wings to offer more resistance to the oil or water, and so lessen the oscillations.[2]

In the brown hematite mines in the vicinity of *Easton, Pa.*, the shafts were only 75 to 200 ft. deep and small in cross-section. The ground tended to move and many of the shafts were crooked and some were twisted, so that the timbering at the top was not parallel with that at the bottom.

In order to get the line through the two wires in the most convenient position, a straight edge was laid across the top of the shaft and the surveyor would go to the bottom of the shaft and sighting upward with the eye, would set the straight edge so that its prolongation would enter the drift at the foot of the shaft. This approximate line was afterward definitely located by a transit on surface, and marked by two nails placed in the shaft timbers. The surveyor, instrument, etc., were then lowered to the bottom, the straight edge was placed against the nails by the assistant, and the plumb-wires and bobs were lowered and placed against the side of the straight edge and as far apart as possible.

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[1] Abstract from "Divergence of long Plumb-lines at the Tamarack Mines," by F. W. McNair, *Eng. and Min. Jour.*, April 26, 1902, Vol. LXXIII, p. 578.

[2] Edwin A. Sperry, *Trans. A. I. M. E.*, Feb., 1894, Vol. XXIV, p. 25.

The wires were tested by holding a lamp on all sides of them and if the assistant on surface could see the light in all positions while sighting down the wire, there could be no obstruction in the way. The base was then located at the bottom by the surveyor with the transit. In 15 shafts thus plumbed, the bases were all between 6 and 18 in. in length.[1]

On the *Comstock Lode*, with the shafts up to 3000 ft. deep, the surveyor did the shaft plumbing with no other help than the miners and the mechanics. He also had to contend with heat, water and drafts of air in the shafts. The plumbing only occupied the shaft from 4 to 5 hr. in each case.

A 2-inch plank about 12 ft. long, with one edge planed straight, was set in line with the transit, across the top of the shaft and cleats were nailed to the shaft collar, and corresponding marks made on both the plank and the cleats, so that it could be replaced in the same position. The plank was then removed and the surveyor and his helpers were lowered to the bottom with their instruments, tubs, plank, etc., and the cage sent up. The mine carpenter replaced the plank, lowered the bobs and wires, set them along the straight edge of the plank as far apart as possible without their touching in the shaft and marked their final position. In the mine, the mean positions of the wires were determined by the shadow method and marked on a white board behind each wire and the base formed by these marks was transferred to permanent points.

If there was any doubt as to whether a wire hung freely, the signal was given to the man at the top to move the wire an agreed distance and it was considered to be free if it moved a like amount at the bottom.[2]

In Montana, the wires were hung in one compartment of a shaft, which was about 1500 ft. deep, and gave a base of about 3 ft. parallel to the short side of the shaft. This position was used as the underground passages approached the shaft at its side. The other hoistway was used for traveling purposes, the cage being run slowly so as not to create a draft.

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[1] Ellis Clark, Jr., *Trans. A. I. M. E.*, Vol. VII, p. 139, October, 1878.

[2] "Method of Carrying a Survey Line Down Shafts," L. F. J. Wrinkle, *Eng. and Min. Jour.*, Jan. 28, 1893, Vol. LV, p. 81.

In lining-in with the wires, the transit was set 35 to 40 ft. away from them. The far wire was illuminated by candles set near it and behind a screen. These candles also illuminated a white horizontal base which projected 2 in. to one side of the screen and gave a white ground on which the near wire appeared as a black line. This device enabled the surveyor to distinguish the two wires and tell at which he was looking.[1]

On the *Underground Railways of London*, the line was carried down the shaft by plumbing, using steel piano wires, about 15 ft. apart. The one nearest the instrument was No. 24 gage and the other was No. 16 gage. The bobs weighed 30 and 56 lb. respectively, and were hung in buckets of oil. On surface, the transit was sighted on the line point and the near and finer wire was brought into line, a piece of white paper was placed behind it and then the further and larger wire was adjusted until it appeared above and below the paper as a broader continuation of the finer wire across the paper.[2]

On the *Erie Railroad*, for tunnel work near Otisville, N. Y., the alignment was obtained by two wires in the shaft. The bobs were immersed in thick oil. To insure that the wires hung freely, the cage was run slowly up and down the shaft while a man carefully examined each wire. In order to make the wires visible for sighting, a piece of glass with a thin coating of white paint was held behind each wire and illuminated with an acetylene lamp. By holding one glass higher than the other, both wires were visible at the same time.[3]

Other Methods of Locating Wires in the Mine.—It sometimes occurs that it is impossible to set the transit in line with the wires if the base through them extends the long way of the shaft, and if the base is arranged across the shaft, it is too short for accurate work.

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[1] "Method of Transferring Surface Alignment Underground," L. Kuhn, *Eng. and Min. Jour.*, Feb. 25, 1893, Vol. LV, p. 179.

[2] *Eng. Rec.*, Sept. 3, 1904, Vol. L, p. 289.

[3] Abstract from *The Polytechnic* in *Eng.-Con.*, March 11, 1908.

One method used in this case is to place the wires at the ends of the shaft and then transfer the base line by means of T-squares to a position outside of the shaft where the transit can be set up. Typical conditions at the bottom of a shaft where this method is required are shown in Fig. 130. If the compartments are 5 or 6 ft. wide, a base of 8 or 10 ft. can be obtained by using two of them.

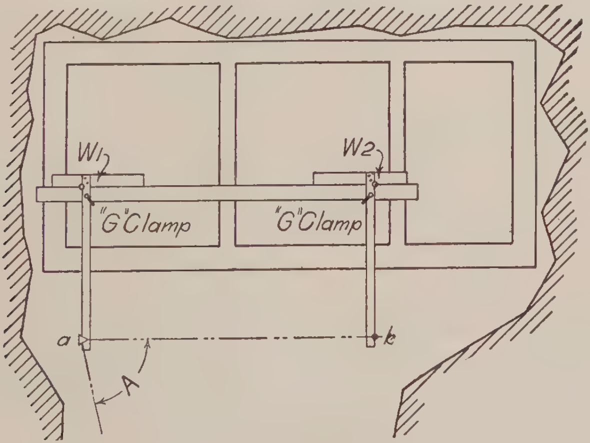

Fig. 130.—Transferring the base to one side.

The mean position of the wires, W_1-W_2, are found and a horizontal wooden straight edge is placed in line with these points and fastened to planks nailed to the shaft timbers. Two wooden T-squares with blades long enough to reach outside of the shaft, and with heads as long as can be used, are placed against this straight edge, and clamped to it at the mean position of the wires. Each of the T-squares has a mark on it at the same distance from its head, the line through these points *a* and *b* is then parallel to the one in the shaft, and is used as the base. The distances from the head to the marks on the blade must be measured with great care as any error in these distances will seriously affect the position of the base. The T-squares need not be square, if it is more convenient to project the line obliquely but they should both be as nearly alike as it is possible to make them, a small error, however, in the angle of one of the squares would not seriously shorten the distance between the two lines or materially affect the alignment of the base. Having obtained this auxiliary base, the transit may be set over one of the points as *a*, using the other as the backsight, and the angle *A* between the base and the first course in the mine can be measured thus orienting the mine survey. The angle W_2-W_1-a, and the distance W_1 to a must be known in order to find the coordinates of the point *a* with respect to the surface origin.

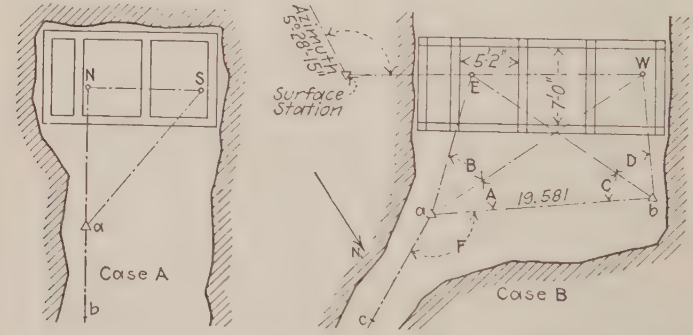

FIG. 131.—Locating the wires by triangulation. Case B shows the lines at the 11th level, 4427 ft. below surface, at No 4. shaft, Tamarack Mine, near Calumet, Mich., 1902.

This method was used on the Comstock Lode in carrying alignment from one level to another in the mine and from the surface down shafts some of which were 3000 ft deep.[1]

A second method is to set up the transit outside of the shaft; to measure the angles to the mean positions of the wires and the lengths of enough lines so that the triangle between the instrument and the wires can be solved by trigonometry, see Fig. 131;

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[1] L. F. J. Wrinkle, *Eng. and Min. Jour.*, Jan. 28, 1893, Vol. LV, p. 81 .

then to connect one side of this triangle to the first course of the mine survey, and to calculate the azimuth of this first course and the coordinates of the first point.

Two general methods of procedure are used: first the angles are read from one point and second, the angles are read from two points.

By the first, a single transit station is used as in Case A, the angle *N-a-S* is read by repetition and the distances *a-N* and *a-S* are measured. Then these distances are used with the angle *N-a-S* to calculate the other angles of the triangle, and knowing the direction of the line *N-S*, the azimuth of *N-a* can be calculated, and if this line has been prolonged to *b* and marked the azimuth of the course *a-b* and the coordinates of *a* are known. If *a-b* is not a prolongation of *N-a*, then the angle *N-a-b* must be read. The angle *S-a-b* and the distance *N-S* may also be measured and used as a check on the observations and calculations.

By the second, two transit stations are used, as shown in Case B, at *a* and *b*. The east and west wires are marked *E* and *W*, respectively. The same transit may be used on the two points in succession or two instruments may be used simultaneously. The angles from the base line *a-b* to each of the wires are read by repetition by both instruments, thus the angles, *A*, *B*, *C*, and *D* are obtained. The base *a-b* is measured. Then all the remaining angles and the distances can be calculated, giving several determinations of the direction of the base *a-b*. The angle *F* between the base and the first course *a-c* must be measured, in order to orient the mine survey.[1]

A great difficulty in these triangulation methods is to measure the distances exactly. The accuracy of the entire calculation depends largely on this, as a slight error makes considerable difference in the angles. One man measured the base with a leveling rod, taking six or eight readings and averaging the results.

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[1] This method was used at the Tamarack Mine, and described in *Eng. and Min. Jour.*, April 26, 1902, also used by T. Lane Carter in the Johannesburg, So. Afr. gold fields and described by him in *Eng. and Min. Jour.*, Oct. 11, 1902.

Several Wires in One Shaft.—Where the transit cannot be set in line with the plumbing-wires, a method using four wires has been developed by the Philadelphia & Reading Coal & Iron Co's. engineers, as affording greater accuracy than triangulating to two wires, see Fig. 132.

The surface survey is carried to a point *A* which is over the underground connection to the shaft. The transit is set at this point, cords are stretched and positions for the guides for the wires are marked at *B*, *C*, *D*, and *E* with chalk. The guides *C* and *E* on the further side are set and then the near guides *B* and *D* are set on the lines from the transit to each of the further ones. These guides are made of ½ by 2 in. flat iron by 16 in. or more in length. They have a smooth notch filed in their outer end through which the wires may be lowered and have holes near the other end through which spikes may be driven, holding them to the shaft timbers. The azimuth of each line, *A-B-C* and *A-D-E*, is determined and the distances from *A* to each wire and the distances *B-C* and *D-E* are measured. In shafts that are exactly plumb, the wires may be hung in the space between the

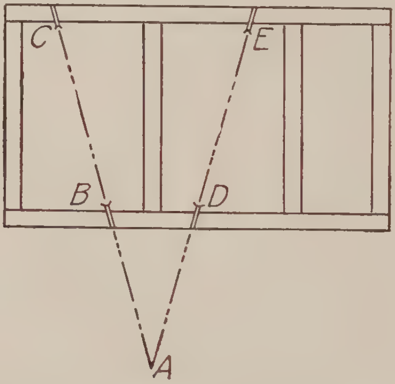

Fig. 132.—Plumbing with four wires.

cage and the side timbers, then the cages can be lowered and the examination of the wires can be easily and thoroughly done. At the bottom, after the wires have settled or the mean positions have been determined, cords are stretched parallel to the wires and the transit set at the intersection of these cords, and shifted until exactly in line with both pairs of wires. The distance from the transit to each wire and the distances between the wires of each pair are measured and the included angle *C-A-E* is read by the transit. These should all agree closely with the corresponding surface measurements if the work has been carefully done.[1] One line, as *A-C*, is then connected with both the mine and the surface surveys.

USE OF PLUMB-LINES IN INCLINED SHAFTS

There are some cases with inclined shafts or combinations of inclined and vertical shafts where plumb-wires can be used to advantage to carry the alignment into the mine.

If a mine is worked by a vertical shaft which extends down to the vein and then turns and follows the vein, the alignment may be carried down by plumbing through the vertical portion, and then setting the transit in the inclined portion, observing the wires and marking the line through them on the principle used where the connections at the bottom of the shaft were horizontal, except that the instrument work will be done on an incline. This is shown in Fig. 133.

If a steep inclined shaft is to be surveyed, and the transit is not equipped for steep inclined sighting, the line can be carried down by an inclined wire stretched in the shaft so as not to touch anywhere,[2] see Fig. 134. The direction of the line may be determined by surface observations, and this direction can be again observed in the mine, and transferred to permanent marks, giving a base for the mine surveys. Plumb-bobs may be used to give a longer horizontal base for determining the direction of the wire, than could be obtained by sighting on the inclined wire directly. Such plumb-lines must be tangent to the same side of the inclined wire and to facilitate the shifting of them sidewise, a simple guide as shown in the corner of the figure will be needed. A block is attached to a timber nearly over the wire and a lag screw with a grooved spool on it is screwed into the block then by rotating the spool the plumb-line will be shifted sidewise. The coordinates of the lower end of the wire must be obtained by measuring the length and inclination of the inclined wire. The inclination, however, can only be obtained approximately either by use of similar triangles or by a clinometer as used with the hanging compass, hence the coordinates of the lower end will only be approximate. Any plumb-lines that tend to vibrate must be steadied in buckets of water.

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[1] "Plumbing Shafts," by Geo. B. Hadesty, *Col. Eng.*, Aug., 1896, and reprinted July, 1897.

[2] Used by H. H. Holbert in Rico Mine, British Columbia, and noted by Joseph Barrell, *Mines and Min.*, Jan., 1899.

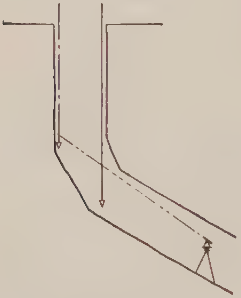

Fig. 133.—Plumbing a combined vertical and inclined shaft.

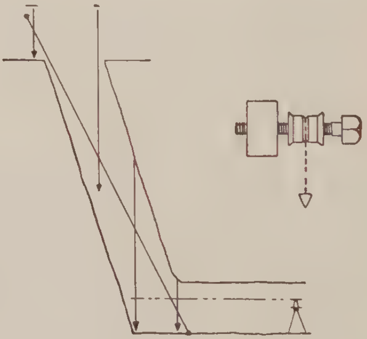

Fig. 134.—Use of an inclined wire.

The bent plumb-line is an ingenious device for carrying a vertical plane down a shaft of varying inclination. It depends on the principle that a cord deflected by weights at various points into a polygon hangs in a vertical plane through the points of support, and by varying the position and size of the weights a concave polygon of any shape may be formed. Thus Fig. 135 illustrates some of its applications. The vertical plumb-lines are used to increase the base for determining the direction of the inclined wire. The difficulty of obtaining the coordinates of the lower end of a bent line will be greater than obtaining those of a single inclined line, but the same method, namely, taping the length and measuring the inclination with a clinometer will be applied to each side of the polygon in succession, and the sum of the various horizontal and of the various vertical distances will give the total horizontal and vertical distances between the ends of the bent line.

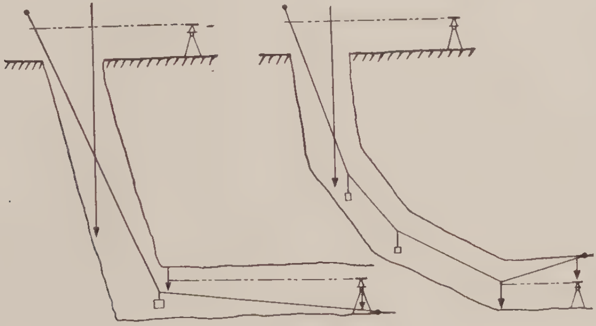

Fig. 135.—Bent plumb-lines in inclined shafts.

The bent plumb-line must be protected from drafts the same as vertical plumb-lines and the weights may have to be hung in tubs of water.

MEASURING THE DEPTHS OF SHAFTS

It is necessary to measure the depths of shafts in order to determine the elevations of the underground workings with reference to the surface datum. The elevations, as determined by the surface survey, are carried to the top of the shaft, a bench-mark is set on some convenient timber, and other marks are set at the different levels and at the bottom, directly under the surface bench-mark. Then the vertical distance measured down the shaft, subtracted from the elevation of the bench-mark at the top, gives the elevation of the mark in the mine. From these marks, the elevations can be transferred by ordinary leveling methods to a permanent bench-mark in each level or to a traverse station from which the elevations of other points can be readily determined.

The vertical distance between the two shaft marks can be measured in the case of shallow shafts by stretching a steel tape between them. This will seldom be practical for a greater depth than 500 ft. as tapes of sufficient length are not usually available.

A convenient method where the shaft is deeper than the length of the tape is to measure down one of the guides used for the cages. To do this, the surface bench-mark is set on the side of the guide, the zero end of the tape is hooked over a nail driven at this mark, the cage is lowered slowly allowing the tape to unwind from the reel on the cage until the desired length is unwound, when the cage is stopped, a nail is driven into the guide and the distance from the previous point is read and recorded. The cage is then hoisted, the tape is rewound, and the zero end is unhooked when it is reached. The cage is now lowered to the lower nail, the zero of the tape is hooked on and another length is measured down the shaft. These operations are repeated until the whole depth of the shaft has been measured.

The nails must be driven on the side of the guide where they cannot be struck by the shoes of the cage sliding along the guide. A light should be left near the lower nail while the cage is being hoisted to release the zero end, so that it can be found easily when the cage is lowered again; a white rag tied to the nail would answer the same purpose. The cage usually has a hood and other mechanism that may interfere with the tape and prevent the holding of it close to the guide, so it is convenient to build a platform on top of the cage on which the men making the measurements can ride. A convenient party will be three men, one to manipulate the tape, a second to attend the signal wire, and give the signals to the engineer to hoist or lower, and a third to record the distances. The first two will ride on the platform above the cage and the recorder can ride in the cage.

A special device has been proposed for measuring the depth of a shaft consisting of an accurately turned wheel over which a wire passes on it way down the shaft. The wire is lowered into the shaft and weighted after it has stretched as much as it will, a mark is made on the wire opposite the bench-mark at the bottom and the wire is hoisted until the mark coincides with the bench-mark at the surface. Then the number of revolutions of the wheel multiplied by its circumference gives the distance between the two marks.[1] The apparatus to be accurate would be expensive and as it would only be used occasionally, its purchase would not be warranted.

The depth of a shaft may also be determined by measuring the length of the hoisting rope. A mark is placed on the rope opposite a point of known elevation at the surface and another opposite a point in the mine. A man is stationed near the engine house and another in the top of the head frame, where they can reach the rope. The cage is then hoisted until the surface mark on the rope reaches the lower man, near the engine house; the upper man places a mark on the rope; the distance between the marks is measured and recorded; the cage is then hoisted until the rear mark just made reaches the lower man, when another length is measured. This is repeated until the mark on the rope made in the mine reaches the surface, then the distance from the last mark made by the upper man to the mine mark is measured. The sum of all these distances gives the distance between the two bench-marks. This method is probably not as accurate as measuring down the guides, as the marks are coarser and may slip.

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[1] *Brathuhn, Berg- und Hütten-mannische Zeitung,* 1898.

CHAPTER XII

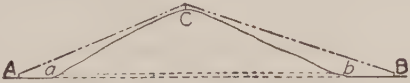
TUNNEL SURVEYS

Tunnel surveys differ from most underground surveys in that they are made as a guide to the driving of the tunnel on a predetermined course, instead of being the survey of an excavation already made. Tunnels are usually driven straight in order to make them as short as possible, but sometimes it is necessary to introduce a curve or an angle in them in order to make them fit the local conditions.

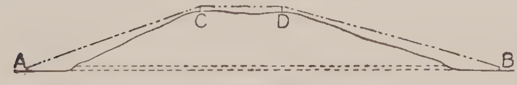
Preliminary Survey.—This consists of a survey between the two ends of the proposed tunnel and from it is determined the direction, the length and the grade of the tunnel. It is the first step in laying out the line of the tunnel.

The simplest survey occurs where the tunnel is to be driven straight through a hill of such shape that a point near each portal can be seen from the summit, as in Case I, Fig. 136. Then signals are set at both *A* and *B*, and a point *C* is found on the line *A-B* that is visible from both *A* and *B*. The approximate position of *C* may be found by two men each with a range pole, each man alternately shifting his pole until both poles appear to both men to be in line with the signals *A* and *B*. The transit is set up in line with the two range poles and shifted sidewise until both points *A* and *B* can be seen, by simply reversing the telescope. The instrument should be level and in perfect adjustment and the correctness of its position should be tested by taking the sights on *A* with the telescope alternately normal and reversed. When the position of *C* is finally determined, a permanent monument and target is erected at this point. The transit is next set at *A* and at *B* the directions of the tunnel at these points are obtained by sighting on *C*; then on dipping the telescope toward the hill, the starting points *a* and *b* are located. Permanent monuments are established at *A* and *B* from which to start the tunnel surveys.

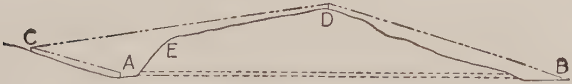
When the hill is a broad one or there are obstructions, it may not be possible to see both portals from a single point, then the line of the tunnel must be found as the "missing side" of a meander traverse, and the calculated course should be verified by running the line from one portal over the hill to the other. Sometimes it is more convenient to run a straight random line over the hill from one portal toward the other, to find the error in closure and then to run a new line on the corrected direction. After the line has been determined, targets are placed so that one can be seen from each portal, as at *C* and *D* in Case II. In Case III, the hill rises abruptly from *A* and if a target is placed at *E*, the sight *A*-*E* will be short and steep, hence a more satisfactory sight is obtained by setting the permanent line target at *C* outside of the tunnel portal. Both of these conditions are shown in the tunnel profiles in Fig. 141 and 142.



Case I



Case II



Case III

FIG. 136.—Surface surveys for tunnels.

A survey of the surface on the line of the tunnel should be made in order to determine the cover over the tunnel and to locate the topographic and geological features that might extend downward to the line of the tunnel and have an influence on the excavation. For long tunnels, that are to be worked from several points, the topographic survey should be made for some distance on each side of the line in order to determine the best locations for the intermediate openings, to indicate the relative advantages of using vertical or inclined shafts or horizontal drifts for these openings and to show the sites available for dumping the excavated material.

In very rough country, it may not be feasible or desirable to lay out the exact line of the tunnel on the surface, then its direction must be calculated entirely from the traverse and will be laid out at each portal by an angle measured from the last traverse course. This would be the condition where a tunnel is driven to connect with some mine working or where one is to be driven between two parts of a mine. In these cases, the check survey over the center line of the tunnel could not be run, as one or both portals would be underground.

In laying out a tunnel under a river or in impassable regions, the length and direction may be based on a triangulation survey. This was done for the tunnel under the Hudson River, whereby the Pennsylvania Railroad enters New York City, and for the line of the Simplon Tunnel through the Alps.

In addition to the direction of the tunnel, it is necessary to know its length and the difference in elevation of its two ends. The length can be found by taping over the hill between the portals in simple cases, and in others by calculation from the traverse or from the triangulation system. The difference in elevation between the ends may be based on the vertical height obtained by the traverse but it is better to carry a line of exact levels over or around the obstruction from one portal to the other so that the grade on which the tunnel is driven may be based on exact data. The amount and direction of the grade depends on the purpose of the tunnel; they are often of great moment. If the tunnel is to carry water by gravity, it must have a grade that is constantly down in the direction of the flow. If the tunnel is for a railroad, it may be desirable to have it level, but it must still have a slight grade for drainage toward points at which the water can be discharged;

at other times, a difference af elevation must be overcome, then a certain grade will be necessary and must be accurately maintained to accomplish the result.

Alignment of a Tunnel.—The direction of a tunnel being marked by the survey monument at the portal and the line target, and the initial point having been located, the excavation is begun. When it has advanced a ways, the transit is set over the portal monument, the telescope is oriented by the line target and spads are set on the center-line, either in plugs in the roof or in the caps of the timbering, so that the tunnel foreman can hang cords, with a weight attached, from them and by sighting past the cords keep the tunnel excavation on line. The inner spad should be kept as close to the face as possible so that the tunnel shall never be driven far by these rough sights.

The surveyor must also set instrument points that are absolutely on line, as determined by a number of observations, from which to continue the line of the tunnel. These must be kept far enough back from the face to be safe from the blasts. In a straight tunnel on a uniform grade, a target at the portal monument will appear in line with all the instrument stations when viewed from the inner end of the tunnel, if the work has been accurately done.

On important tunnels, the instrument stations often consist of two parts, one that is fixed and driven into a plug in the roof and a second that can be moved horizontally across the first and from which the plumb-bob is hung. The relation of the two parts is indicated by a scale. The line of the tunnel is determined a number of times, the position of the scale being noted each time and the mean of the several observations is taken as the final position of the line. The sliding part is then fixed in this position and so used in prolonging the line. Several of these scales are shown in connection with the descriptions of special work, see Fig. 146, 149 and 155.

If there is to be a bend in the tunnel, the angle in the center line is turned off as accurately as possible and the forward station set, after which the angle thus made should be measured by repetition and if the mean of several sets shows the angle to differ from that desired, the forward station must be shifted an amount needed to correct the angle and the angle should then be reread.

If the tunnel is to be curved, its course must be laid out by the same methods as used to lay out railroad curves. These must be rerun until each tangent is known to bear the proper relation to the previous one.

In short tunnels, any good transit may be used and will give close results, if used with care.

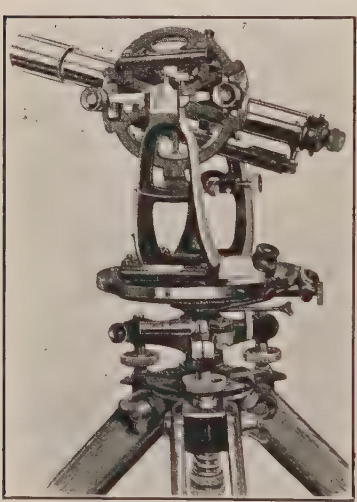


Fig. 137.—Eight-inch transit-theodolite. Made by Buff and Buff Mfg. Co., Boston, Mass.

On long and important tunnels, the exact center line must be carried by a large instrument so that the angles, if there are any, may be read more closely and so that the straight lines may be prolonged more accurately. These instruments are known as transit-theodolites and are often used for triangulation surveys on surface, for city surveys and for similar accurate work. The horizontal plates are from 6½ to 8 in. in diameter and read to fractions of a minute. They resemble the theodolite used for geodetic angle reading, in having stiff standards and cylindrical bearings for the horizontal axis, which type of bearing is more accurate than the conical bearings of ordinary transits and can be used in theodolites as the axes are not depended on to tie the tops of the standards together. They differ from the true theodolite in that the telescope can be "transited," *i.e.*, reversed by plunging. One make of these instruments is shown in Fig. 137.

In tunnel surveys, the instrument is set on the backsight and the line is prolonged by simply plunging the telescope and setting a foresight on this line. In order to eliminate errors in adjustment, the operation is repeated, taking the backsight with the telescope in the reversed position to that used the first time, plunging, and setting a new foresight. If the two positions of the foresight do not agree closely, they should be further checked, but if they are only slightly out, a point midway between them may be taken as the final position of the foresight.

It is usually necessary to carry on the surveying without interfering with the work of driving the tunnel. On small jobs, the surveys can often be made at night or between shifts, but on important jobs, the work of excavating and lining is carried on continuously and the surveying must be done during working hours. In large tunnels, it is usually possible to build a shelf for the instrument and below it a platform for the surveyor, both in the upper part of the tunnel and above the traffic. In a small tunnel there would not be room for a platform for the surveyor but a shelf for the transit might be built above the line of travel, then the transit would remain undisturbed and the surveyor could step to one side, if he was working over the track, to let the cars pass. If necessary the surveyor could stand on a box in order to reach the instrument. Another arrangement would be to place the instrument on a bracket near one side of the tunnel and so be out of the way of the traffic, but a slight projection from the wall might interfere with the sights and a line near the wall is not as convenient for directing the work of tunneling, as one in the center.

A trivet, Fig. 99, is convenient for mounting the transit when using a shelf. Where there is only a limited use for such a stand the surveyor could make one of a triangular-shaped board provided with three-pointed pegs for legs and a block to which to screw the transit; or, the block could be fastened directly to the shelf if it was not desired to shift it.

Aligning a Tunnel through a Shaft.—A long tunnel is often driven in both directions from the foot of a vertical shaft in addition to being driven from the ends. This is done in order to expedite the construction work. The shaft may be useful in connection with the operation of the tunnel.

The shaft is located on the surface either on the center-line of the tunnel or in a position whose relation to the tunnel is known. The simplest case is where the shaft is over the center-line of the tunnel, then when it has been sunk to grade, and the tunnel has been started, two bobs are hung in the shaft, marks are made in line with them, and this base is used to determine the direction of the tunnel for a short distance in each direction. If the shaft is sunk at one side of the line, the tunnel is reached by a cross-cut, and the points for starting the tunnel will be marked on the walls of this cross-cut. When the tunnel has progressed

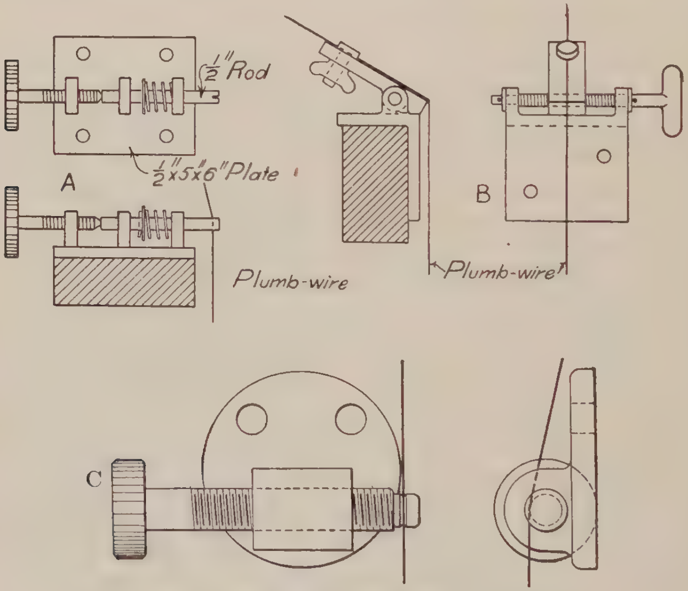


Fig. 138.—Adjustable guides for plumb-wires.[1]

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[1] Style A, *Eng. and Min. Jour.*, Feb. 25, 1893, Vol. LV, p. 179. Style B, *Proc. Inst. of C. E.*, Vol. CXLII, p. 334. Style C, G. H. Potter, catalog of C. L. Berger and Sons.

a short distance the shaft is more carefully plumbed and the center-line is marked with temporary points set with the transit, and used until the tunnel has advanced far enough to allow a permanent base, say 200 ft. long, to be established where it will not be disturbed. Then the shaft is very carefully plumbed and the center-line is established in the tunnel with the most accurate instruments available. This latter work is repeated several times and the mean of the results is taken as the final line.

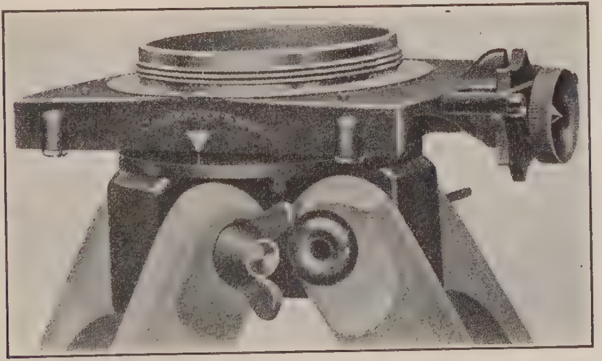

Fig. 139.—Lateral adjuster. Made by C. L. Berger and Sons, Boston, Mass.

In mine surveys, any line may be transferred down the shaft, provided its azimuth is known, but in tunnels where the shafts are on the center-line, this line is plumbed down, then when the transit is set up on the line through the wires at the bottom, the center-line is established in the tunnel without angle work or calculation. To facilitate the setting of the plumb-wires on the center-line, the guides that hold the wires at the top of the shaft are made adjustable, so that the wire can be shifted sidewise and brought to the exact line. Fig. 138 shows three designs. These are attached to planks placed across the shaft. The sliding piece in style A is moved forward by a screw and against the resistance of a spring. Style B has a thumb screw by which the wire can be clamped and so combines a clamp and a guide.

In setting a transit in line with two plumb-wires already in position, the shifting head can be used for a small movement; its use requires the loosening of the leveling screws, which affects the level of the instrument and the motion is less than $\frac{1}{2}$ in. To increase the possible movement and still retain the instrument in a level position a lateral adjuster, Fig. 139, is made, which can be applied to either a tripod or a trivet and would be useful where much work of this kind has to be done.

RAILROAD TUNNELS

Simplon Tunnel.—The Alps form a natural barrier to the communication between the various countries of central Europe, and have been pierced by numerous tunnels for the railroads.[1]

The Simplon Tunnel through the Alps is the longest railroad tunnel in the world. It is 12$\frac{1}{4}$ miles between portals and consist of a tangent about 12 miles long with a short curve at each entrance. As the curves at the ends would have complicated the surveys, small drifts were driven to prolong the main tangent to the surface. These drifts had a combined length of 1338 ft. The tunnel consists of two bores 17 m. (55.76 ft.) center to center and with a maximum finished cross-section 5.9 m. high by 5 m. wide. They were connected at intervals by cross drifts to facilitate the ventilation and for the safety of the men while the work was in progress.

The survey for the alignment was made in 1898, by triangulation. A sketch of the survey net and a map of the country are shown in Fig. 140. The net was made double so that either side would give a solution of the problem by itself and together one side would check the other. The survey was connected with the stations of the geodetic survey of the Swiss Government at Faulhorn and at Wasenhorn; this saved the work of making a precise base measurement. In utilizing the governmental survey, allowance had to be made for the elevation of the tunnel of 633 m.

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[1] See "Commercial Aspects of Present and Proposed Alpine Tunnels," *Eng. News*, Dec. 5, 1907, Vol. LVIII, p. 613.

above sea level, as the sides of the Federal triangulation had been reduced to sea level as usual. This correction in the computed length of the tunnel as derived from the triangulation was very nearly 2 m. in amount.[1]

The survey stations were marked by masonry columns which were 0.9 m. in diameter at the base, were set 1 m. below the surface, were carried to a height of 1 m. above the surface and were 0.5 m. in diameter at the top. They were capped with zinc cones 2 ft. high which could be removed for setting the instrument. Two different theodolites were used in the course of the survey, one having a limb, 8 in. in diameter and the other 9 in. in diameter. The station at Mont Leone was at an altitude of 11,670 ft. and that at the south axis was 2076 ft. above sea. The portal stations figured 19,756.31 m. apart.

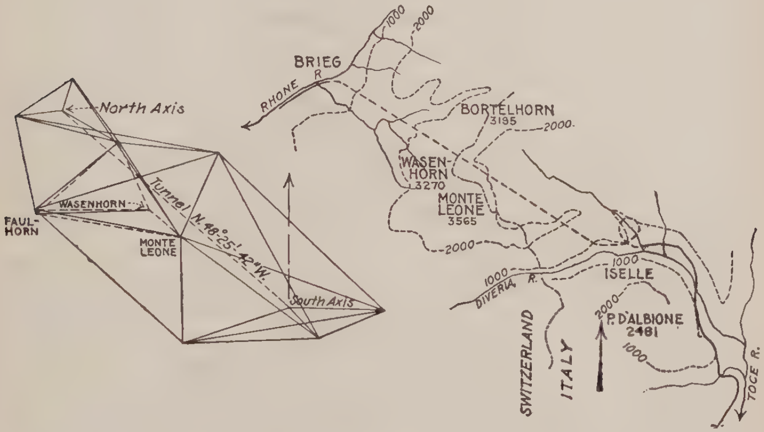

Fig. 140.—Map and triangulation net of the Simplon tunnel. Elevations are in meters.

Each portal station was connected with three triangulation stations. Direction marks were placed on the line of the tunnel at each end. These consisted of iron boxes having slits covered with milk glass. The width of the slit was governed by the distance of the box from the instrument. At the north end, the marks were 1840 and 2450 ft. distant and the slits were 0.8 in. in width. At the south end the marks were only 302 and 174 ft. distant, owing to the narrow valley, and the slits were 0.08 in. wide. These targets were visible by night or day and were set in niches in such a way that they could be locked up.

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[1] A similar correction would be needed if our own government triangulation system should be utilized for any refined measurement at a place where the elevation of the country is considerable.

After tunnel points had been lined in at about 500 m. (1640 ft.) from each end, these and the direction marks from which they were derived, were tested by careful measurement of the angles between them and the trigonometric stations visible from the portal stations. These tests were repeated a great number of times and at various seasons, in order to insure the accuracy of the alignment.

After reliable direction points had been established in the tunnel the line was prolonged by using a transit whose telescope could be removed from its standard and the ends of the axis transposed so as to eliminate errors of collimation.

The targets were acetylene lamps mounted on stands, each provided with a movable sighting slit. The position of the slit could be read on a scale and could also be marked on a strip of paper as a check. The alignment was determined by at least eight sights in each position of the telescope. At first, the line was accurately advanced every six months but later it was brought up at yearly intervals.

Very long sights from the observatories into the tunnel were unsatisfactory owing to the distortion of the image caused by the change of refraction when the line of sight entered the tunnel. On the other hand, when the sights were taken in the tunnel, the irregularities of the image were found to be comparatively small and sights 2½ miles long could be taken. This stable condition was due to the excellent ventilation.

The elevations at the portals of the tunnel were based on two lines of precise levels run between Brieg and Iselle over the Simplon Pass in 1870 and 1873, the lines being each 29 miles long.

Check levels were run over parts of this line between 1898 and 1902.

The measurements of distances within the tunnel were made at first with 5 m. rods, but the method was too slow and required a large force, so later, the measurements were made by a wheel 3 m. in circumference rolled along one rail of the finished track. Four repetitions of these measurements were made, and the probable error was about 0.50 ft. per mile.

The tunnel holed through on February 24, 1905, and check surveys were made in August. The error in closure of the tunnel in distance was 0.79 m. (2.59 ft.); the lateral divergence of the axes as prolonged from the two ends respectively was 0.202 m. (0.663 ft.); and the difference in elevation at the meeting point was 0.087 m. (0.285 ft.).[1]

Hoosac Tunnel.—This tunnel was driven through mountains in the western part of Massachusetts between 1865 and 1875. It was excavated from both ends and from a center shaft. A small shaft at the west end was used to start work at that end but did not affect the general method of the survey.[2] The location of the survey points used and the principal dimensions are given in Fig. 141.

At the shaft, a frame with a movable slit was firmly bolted to a foundation on each side of the opening.[3] The slits were brought into line by a number of observations, their positions were noted each time by means of attached verniers and they were finally set on the mean position. Two fine steel wires were then stretched across the shaft between the sides of the slits and between these were lowered the plumb-wires, 25 ft. apart. The wires were enclosed in boxes to protect them from falling water and air currents. At the bottom, the mean positions of the wires were determined by horizontal scales placed behind the wires. The line through the wires was then transferred to wooden or metal scales fastened to plugs set in holes in the roof. The scales were divided into decimals of a foot and plumb-lines could be moved along them until on the correct line when their positions were read and noted. The final line was taken as the mean of the reliable observations.

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[1] The above is abstracted from "Triangulation and Construction Survey for the Simplon Tunnel," by Horace Andrews, *Eng., News*, Dec. 21, 1905. The Simplon Tunnel is fully described in a serial article in *Eng. News*, Aug. 13, 20, and 27, 1903, which shows the interesting engineering features, as the terminal curves, and a helical tunnel on one of the approaches but there are no details given of the surveying.

[2] The first rock drills of the reciprocating piston type, driven by compressed air, were used to drive this tunnel and the experience there obtained did much to develop them into a practical machine.

[3] Abstract from "Laying out Tunnels; Shaft Plumbing" in "Manual for Railroad Engineers" by Vose, 1874 edition, page 69.

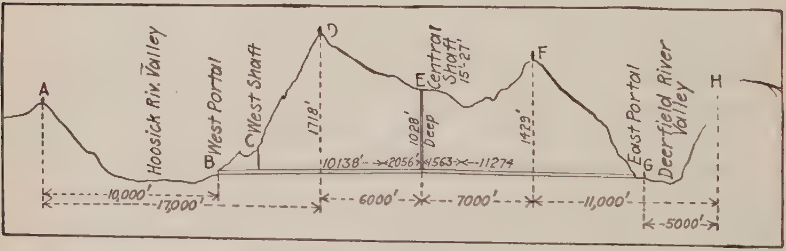

FIG. 141.—Profile of the Hoosac tunnel. Tunnel is 20 ft. high × 24 ft. wide × 25,031 ft. long. Central shaft is 15 ft. × 27 ft. in section.

The positions of the meeting points are given in the figure and the errors in alignment at these points were 0.045 ft. on the west and 0.025 ft. on the east side of the shaft. The error in grade was $1\frac{1}{4}$ and $1\frac{1}{2}$ in. on the east and west respectively.

Musconetcong Tunnel.—This tunnel is in the western part of New Jersey, on the Lehigh Valley Railroad, was built in 1872–74 and was driven from the two ends. The profile with the location of the survey points are given in Fig. 142. The point *A* was established on the summit on the center-line and then stations *B*, *C*, and *G* were set. The shafts *E* and *F* and incline *D* were needed to overcome local conditions but are not important in this discussion. The positions of the permanent monuments were determined a number of times, by night and by day, in both summer and winter, and the mean position used as the final one. The sights were up to 1¼ mile in length. The targets were ½-in. round iron rods painted white and answered very well but the most satisfactory signal was a plummet lamp with a flame ¾ in. high and ⅓ in. in diameter viewed on clear calm nights.

Over the mountains the chaining was done horizontally. Two movable frames each consisting of a vertical staff and provided with three legs were used to hold a plumb-line. These plumb-lines were set on line by the transit, the distance was measured from the foot of the upper plumb-line to a point on the same level on the lower one, using a steel tape, then the rear frame was moved ahead and the operation repeated.

When the headings met, the levels were out 0.015 ft. and the measured distance agreed within 0.52 ft.[1]

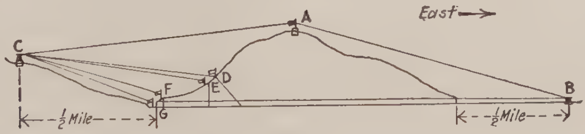

FIG. 142.—Profile of the Musconetcong tunnel.

Cascade Tunnel.—This is on the Great Northern Railway, and replaces the switch-back at Stevens Pass where the railroad crosses the Cascade Range. The location of the tunnel and the saving made in the length of the line are given on the map, and the profile shows the country over the tunnel, Fig. 143. It was finished in 1900.

The positions of the portals were established and then transit stations were set on line on the two peaks in such positions that the portal stations could be seen. The work was checked until there was no apparent error. Timber towers 16 ft. high were then set on each summit and a target consisting of 2-in. gas pipe 20 ft. high was erected in the center of each frame, so as to be seen in winter above the deep snows. These targets were plumbed occasionally by dropping a plumb-line through the center of the pipe to the tack below which marked the point. Intermediate backsights were then located on the mountain side, to be used when the summits were hidden by clouds. Permanent transit points were built at each portal and roofed over to protect them, and from these portal points, the center-line was projected into the tunnel.

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[1] Abstract from "The Musconetcong Tunnel," by Henry S. Drinker, *Trans. A. I. M. E.*, Feb., 1875, Vol. III, p. 231.

The elevations were carried between the two ends by lines of levels run over the old switch-back.

The distance along the line of the tunnel was measured by a 400-ft. steel tape. The measurements were made along the slope of the mountain, between points nearly 400 ft. apart. The points were rigid, being placed on stumps, on braces nailed to trees, or on plugs set in holes drilled in the rock. They were high enough above ground so that the tape hung free when stretched by a spring balance to the standard tension. The measurements were made on cloudy days when there was little wind. The temperature was noted at each end of the tape. The elevations of these measurement points were carefully taken with a spirit level, and then from the inclined tapings, corrected for temperature, and the vertical distances, the horizontal distances were calculated. A base line was laid out at the west portal with a standard 100 ft. steel tape, in order to determine the proper tension to be applied to the 400-ft. tape and fractions thereof, to make it of standard length at a normal temperature of 62° F.

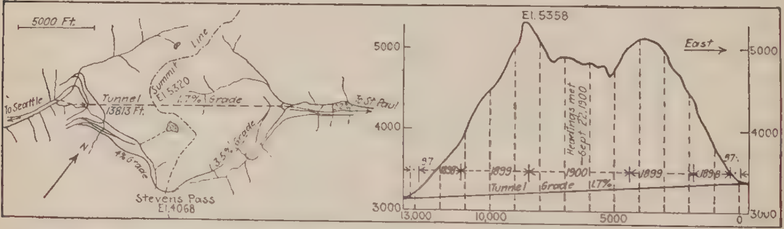

FIG. 143.—Map and profile of the Cascade tunnel, Great Northern Ry.

Inside the tunnel, the measurements were carried along the plumb posts of the timber lining and after the concrete lining was completed the measurement points were marked by plugs set in the concrete walls. Bench-marks were placed in a similar manner. Transit points were placed in the key segments of the timber arch. These were about 800 ft. apart and a platform was built for the surveyors at these points with a separate support for the transit, so that muck trains could pass below them without interference.

On meeting, the errors were: in alignment 0.020 ft., in grade 0.019 ft., and in distance 0.179 ft.[1]

AQUEDUCTS AND SUBWAYS

New Croton Aqueduct, New York.—The water supply of New York City for many years has come from the Croton River. The old aqueduct becoming inadequate, the "New Croton Aqueduct" was started in 1885. It extends from a gate house at Croton Dam to a distributing gate house at 135th St., New York City, and consists of the following:

Rock tunnel, not under pressure, horseshoe section, 13.53 ft. high ×13.6 ft. wide inside of lining	22.80 miles.
Rock tunnel, under pressure, circular section, 14.25 ft. to 10.50 ft. in diameter inside of lining	6.83 miles.
Built in open trenches, six cuts, whose respective lengths are 84 ft., 733 ft., 1312 ft., 123 ft., 459.2 ft., and 3215.5 ft. =5926.7 ft	1.12 miles.
Total length	30.75 miles.

The circular sections were for the tunnel under the Harlem River where it is 307 ft. below mean high tide [2]

The New Croton Aqueduct was driven from 42 vertical shafts and 9 portals; the latter occurring where deep ravines crossed the line. The numerous shafts made it necessary to carry most of the alignment down them by plumbing, and to facilitate this work they were set with their longer dimensions parallel to the center-line of the tunnel and overlapping it a few inches. This arrangement enabled cars to pass the foot of the shaft and also allowed the surveyors to hang the plummets in the spaces in the corners of each shaft reserved for this purpose, out of the way of the cage and still have them on the center-line of the tunnel, see Fig. 144. The larger shafts were $17\frac{1}{2}$ ft. long and the smaller ones 11 ft. long, and as they were kept plumb during sinking by bobs in each corner, these dimensions afforded good lengths of bases for establishing the tunnel alignment.

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[1] Abstract from "Cascade Tunnel, Great Northern Ry.," by John F. Stevens, *Eng. News*, Jan. 10, 1901, Vol. XLV, p. 23.

[2] Above data is taken from "Notes on the Excavation of the New Croton Aqueduct," by P. C. Carson, *Trans. A. I. M. E.*, Sept., 1890, Vol. XIX, p. 705. This paper contains a profile of the entire aqueduct.

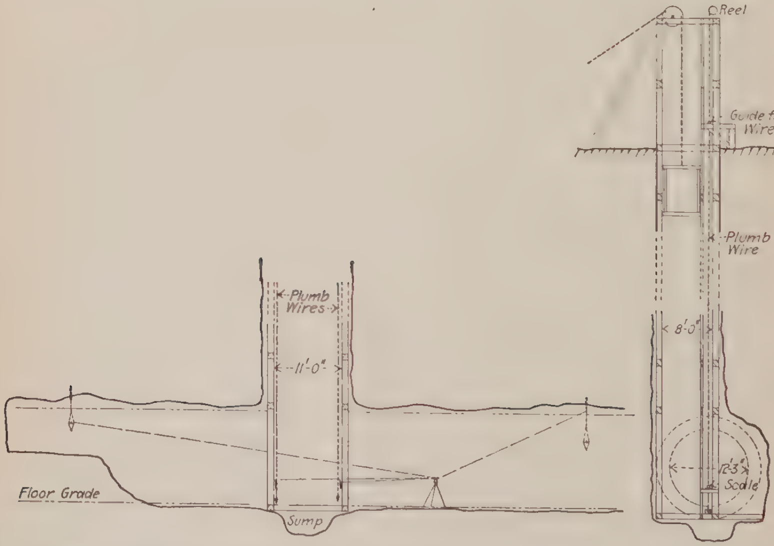

FIG. 144.—Shaft-plumbing, Division 6, New Croton Aqueduct, New York.

From the foot of each shaft, the direction was given for 50 to 100 ft. on each side by stretching a cord under the plummets hung in the shaft and marking its position by points in the roof. When the work had progressed further, a more accurate line was given with the transit and later when the work had advanced so that the points would not be injured by blasting, the shafts were re-plumbed with great care and the permanent line established and checked.

Division 6 of the aqueduct extends from the Harlem River north to near the city limits. It is 24,140 ft. long, all tunnel, and was driven from six shafts, varying from 57 ft. to 205 ft. deep. There are three horizontal angles in it, and the grade varies from 0.7 ft. per mile to 15 per cent., the latter occurring where the aqueduct passes under the Harlem River, see Fig. 145.

The surface line was marked by line-targets 6 ft. high by 6 in. wide, painted red and white alternately for each foot in height, the colors alternating on the two sides of their center-lines. They were permanently set and braced. The transit was set on line 40 to 50 ft. from the shaft to be plumbed and pointed on a line target as far away as could be seen; the further wire in the shaft was lined in by the movable clamp, and the near wire was similarly set without moving the instrument or changing the focus. The guides and clamps for the wires were attached to posts set in the ground on each side of the shaft, and so kept the wires free from the vibration of the machinery. The wire used was No. 8 piano wire which had been annealed. It was wound on a reel 6 in. in diameter holding 300 ft. and provided with a crank. The wire was lowered with a 1-pound weight which was changed at the

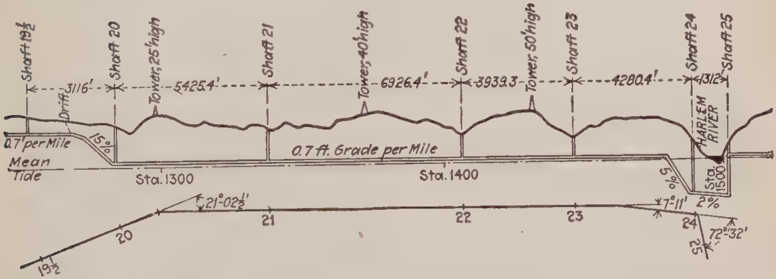

FIG. 145.—Profile and plan, Division 6, New Croton Aqueduct, New York.

bottom for a 25-pound weight, and hung in a bucket of linseed oil, which was covered with boards to keep out falling water. Every foot of the wire was examined by men climbing down the shaft from timber to timber to see that they were free; in some cases the timber had to be notched to give room for the wires. Two or three days were spent in the preliminary work of hanging the wires in each shaft.

At the bottom the positions of the wires were determined and then they were replaced by an illuminated slit. Generally the wires came to rest very quickly, and it was not necessary to bisect their swings. The transit was then shifted until the vertical wire bisected the two luminous slits and the line was transferred to the roof.

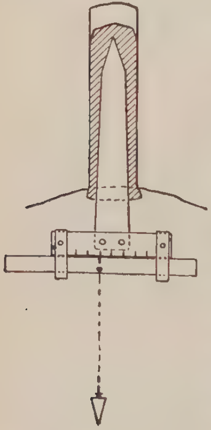

Fig. 146.—Adjustable line point.

For test alignment, points were selected 125 to 150 ft. on each side of the shaft, thus giving a base 250 to 300 ft. long; holes 6 to 8 in. deep were drilled and wooden plugs inserted and into these flat iron spikes were driven to which the adjustable scales were attached, Fig. 146. The plumb-bobs were hung from the zero of the sliding vernier bars, and were brought into line, then the verniers were read. The shaft plumbing and the setting of these vernier scales were repeated until at least three good observations were obtained and then the verniers were set in the mean position and the center-line was prolonged. The settings of the scales that were accepted usually did not differ over $\frac{1}{4}$ in. from each other and sometimes almost agreed.

Levels were carried down by measuring with a tape from a point on the curb to a point at the bottom of the shaft. Bench marks were set in the tunnel and consisted of holes drilled in projecting rock into which wooden plugs and then railroad spikes were driven.

In one shaft 300 gallons of water per minute were pouring down, but by using bull's-eye lanterns to illuminate the slits no serious trouble was experienced.

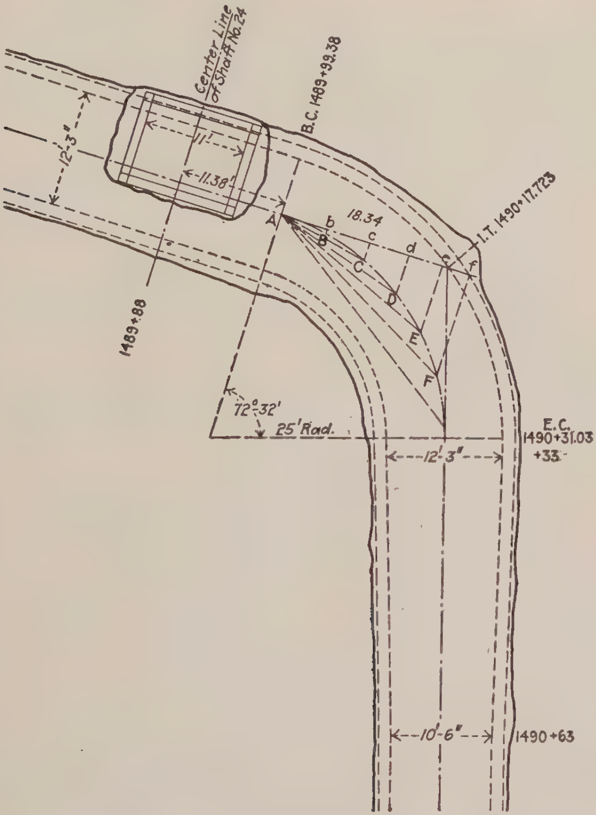

Fig. 147.—Curve at Shaft No. 24, New Croton Aqueduct, New York.

Dimensions of Curve

AB	=	4.99	Ab	=	4.97	Bb	=	0.499
AC	=	9.93	Ac	=	9.74	Cc	=	1.973
AD	=	14.78	Ad	=	14.12	Dd	=	4.366
AE	=	19.47	Ae	=	17.88	Ee	=	7.562
AF	=	23.97	Af	=	21.04	Ff	=	11.489

The curves at the two points where the tunnel was deflected 7°-11′ and 21°-02½′ respectively, had radii of 573 ft. and were laid out by deflection angles for chords of 10 ft., a plug being put in the roof at each point, as the heading progressed. The intersection point of the two tangents in each case fell outside of the tunnel excavation but by cutting out a little of the wall, the transit was set at the intersection point and the angle was observed and checked, thus insuring the accuracy of the new tangent.

The curve with the 72°-32′ deflection had a 25-foot radius. It started so near the wet shaft, No. 24, that the instrument could not be set at the B. C. so the tangent was run out to the I. T. tangent offsets were figured for 5-foot chords and the curve was laid out from these. From the I. T. the new tangent was laid out and checked, and when the E. C. was reached the curve was checked by deflection angles, see Fig. 147.

The following table shows the data regarding the shafts, and the error in the alignment at the meeting points:

Shaft No.	Depth of shaft, curb to invert	Distance between shafts	Error at meeting points
19½	57.0 ft.		
20	138.82	3,116 ft.	....
21	135.51	5,426	Less than 1 in.
22	104.65	6,925	Less than 1 in.
23	86.17	3,940	1⅜ in.
24	205.07	4,280	¼ in.

As the roof of the tunnel was over 15 ft. above the floor, a tripod ladder was used to reach the station points.[1]

Division 5 contained ten shafts with a maximum distance between any two adjacent ones of 2700 ft. In one case there was a reverse curve 823 ft. long, and having 350-foot radii. Owing to the sharpness of the curve only about 150 ft. could be run from one set-up and consequently seven transit points were necessary in laying it out. The headings met about 200 ft. beyond this curve with an error of 1¾ in. (the maximum on this Division), and with apparently a difference of one or two minutes in the alignment.[1]

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[1] Abstract from "Tunnel Surveying in Division 6, New Croton Aqueduct," by F. W. Watkins, *Trans. A. S. C. E.*, Vol. XXIII, p. 17, 1890.

New York Rapid Transit System.—The demand for transportation of persons in New York City having exceeded the capacity of the surface lines and the Elevated Railroad, subways through which high-speed electric trains could be run, were started in 1900 and by 1910 there were 30 miles of them, operated as two independent systems.

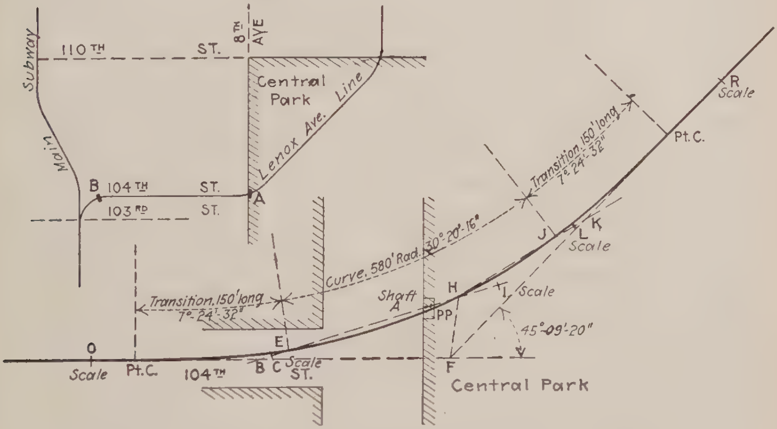

FIG. 148.—Curved tunnel, New York City Subway.

The original system has been added to until it consists of a main line from the Battery to the northwest corner of Central Park where it divides, thence each branch runs northerly, crosses the Harlem River and continues to the city limits as an elevated system. At the southerly end, an extension crosses under the East River to Brooklyn where it has several branches.

The second system consists of four single track tubes under the Hudson River, and of subways in New York City and in Jersey City, each a few miles long, which distribute the passengers to important centers in each city.

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[1] Abstract of remarks by Edward Hegmann, Jr., *Trans. A. S. C. E.*, Vol. XXIII, p. 31, 1890.

The subaqueous tubes, four under the Hudson River and two under the East River, were driven under compressed air, using the shield method. The larger part of the subways on land was built by the cut and cover method through the city streets, but there were a few deep portions of the main system that were constructed by true tunnel methods.

At the *N. W. Corner of Central Park*, a tunnel occurs where the Lenox Ave. line leaves the main line. The tunnel starts near 103rd St., curves to the right 90° into 104th St., which it follows on a tangent, then deflects 45° to the left, passes diagonally under the corner of Central Park and by another deflection of 45° to the left, turns north and approximately parallel to the main line, but a half mile to the east of it, as shown in the corner of Fig. 148.

The curves at both ends of this tunnel were driven partly from the portals, but the middle curve was driven entirely from shaft *A*, and its survey contained samples of all the interesting features of the work on the entire tunnel, so the description will be confined to this portion. The surface survey was complicated by obstacles on the line and the position of wires for plumbing the shaft had to be obtained indirectly but these did not affect the underground surveys, and so have been omitted in describing the location of the wires on surface.

The shaft being near the center of the curve, a point *H* on the curve and near the shaft was chosen and its position with respect to the point of intersection, *F*, was calculated. The direction of the chord through *H* and the end *E* of the circular curve, was calculated from the location survey. The point, *H*, was set on the ground from *F*, and from *B* the angle *F-B-H* was measured as a check on the setting of *H*. The transit was then set at *B* and the wires *P*, *P*, were then hung on the line *B-H* and from their lower end, a chord exactly under *B-H* was established in the tunnel, and marked by scales at *I* and *C*. The points *H* and *E* on the curve and *B* on the back tangent were then located along this line by measuring from one of the wires. The deflection angle between the chord *E-H* and a tangent through *H* was calculated, and the angles to other points on the curve were determined by calculating their deflection angles and subtracting them from this angle. The curve was laid out from *H* by turning off these angles from the chord to the various points; the back tangent was laid out by turning the angles *H-B-O*, and setting the scale at *O* some 300 ft. away. From point *H* another chord, passing through the other end of the circular curve *J*, was calculated, and laid out on the scale *L* by turning the angle *E-H-J;* it was prolonged to the tangent at *K*. At this point, the angle *H-K-R* was turned off, and the forward tangent was located by setting a scale at *R* about 300 ft. from *K*. After the tunnels were connected the survey lines were found to be in error as follows: Under Central Park, 1123 ft. from 8th Ave. shaft and 602 ft. from 110th St. portal, the errors were, in alignment = 0.058 ft. and in grade = 0.021 ft. Under 104th St , 400 ft. from Broadway shaft, *B*, and 1752 ft. from 8th Ave. shaft, the errors were, in alignment = 0.075 ft. and in grade = 0.053 ft.

Fine piano wires were used for plumbing the shafts; they were hung from reels spiked to the shaft timbers and then passed over 1-inch grooved pulleys which had lateral adjustments of ½ in. by means of screws, by which the wires were set in exact alignment. At shaft *B*, the wires were 8.27 ft. apart. At shaft *A*, they were 7.9 ft. apart, 60 ft. long and weighted by 25-pound bobs, hung in tubs of water.

After the wires were adjusted, the transit was set up at the bottom of the shaft and shifted until exactly in line with them. At shaft *A*, the line through the transit was then thrown in each direction in the tunnel and a fine plumb-wire attached to a scale was brought into line, see Fig. 149. The positions of the wires were then read on the scale and recorded. From six to ten settings of the plummet were made and the average position of the scale was taken as the direction of the line. At shaft *B*, the distances to be driven were short and no scales were used in setting the lines.

The observations were taken with the telescope alternately normal and reversed when sighting on the wires and after one set of observations had been taken, with the transit on one side of the wires, it was moved to the opposite side and the observations were repeated so as to eliminate all effects of eccentricity in the instrument. The operations of setting the wires at the top of the shaft were also repeated independently.[1]

At *Fort George*, a tunnel under 11th Ave. extends from 158th St. to the end of the underground work near the Harlem River. It is nearly 2 miles long. It was driven from the two portals and from two shafts, 3,536 ft. between centers, one being at 168th St. and one at 181st. St. These were 103 and 126 ft. deep respectively, and both were at one side of the tunnel and connected with it by drifts about 50 ft. long.

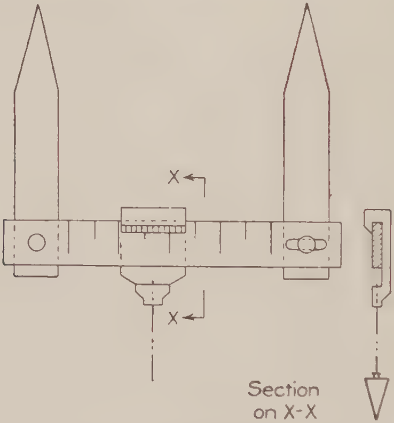

Fig. 149.—Alignment scale.

The work of alignment was practically the same at both shafts and was accomplished as follows: the point of intersection of the main line and the center-line of the drift was located on surface, and a right angle was turned off. This was checked by repetition and resetting when necessary, until correct, see Fig. 150.

The two plumb-wires were then hung in the shaft, and brought to this line. The distance from the main line to the west wire was taped, using spring balances and correcting for temperature.

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[1] Abstract from *Eng. Rec.*, Sept. 19, 1903, Vol. XLVIII, p. 335, and *Eng. News*, Dec. 4, 1902, Vol. XLVIII, p. 478.

In the tunnel, the transit was set up roughly on the line of the two wires, and as far west of the center-line of the main tunnel as possible, in this case about 18 ft., and then "fudged" into the exact line of the two wires. This was a long and tedious process, owing to the unsteady light and the difficulty of keeping the wires steady.

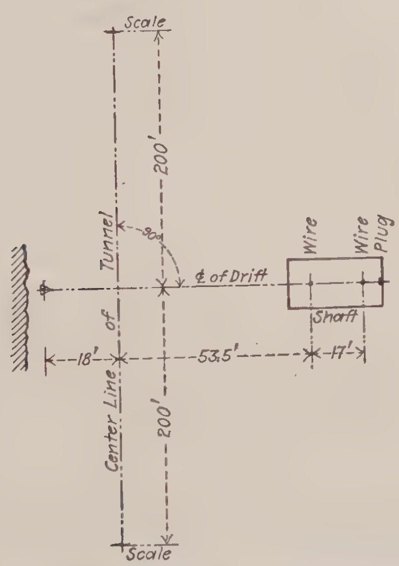

Fig. 150.—Alignment survey, 168th and 181st Street shafts, New York City Subway.

When the transit was accurately aligned with the two wires, a point was marked on a steel spike on the center-line of the main tunnel, and tested both for line and distance, and a second point was set on a plug in the east side of the shaft.

The wires were then thrown off line, and relined by the surface transit. The tunnel transit was also moved off the line, and was again fudged into line with the new position of the wires. New points were then set on both the center-line spike and the plug in the shaft wall.

A mean of the two points on the center-line spike was then marked with a punch mark, and the transit set over it. The mean of the marks on the shaft plug was also punched, and this point used as the backsight. Right angles were then turned for the line of the tunnel by the transit at the center-line spike, and plugs were set in line.

As the tunnel advanced, this angle was turned off again, and a scale set some 200 ft. down the tunnel. The angle to the scale was then read by repetition, and if in error, the scale was shifted until the angle measured exactly 90°. The wires were dropped down the shaft several times and the operations described above were repeated.

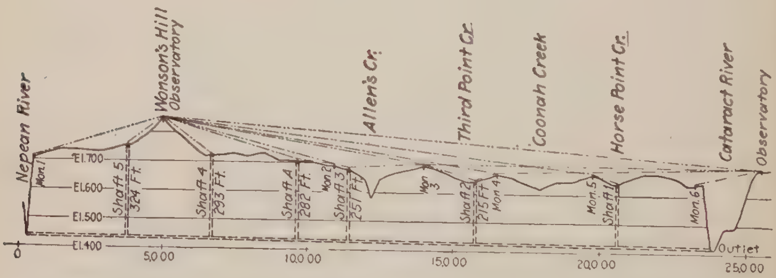

Fig. 151.—Survey for the Napean Tunnel, New South Wales.

For the final line, the mean of all the points on the center spike, and the mean of all the readings on the scales were selected and the line run out, setting points on steel spikes set in the floor.

Owing to the smoky condition of the tunnels, the length of the sights averaged about 150 ft. and were not clear at this distance unless the illumination was extremely good. For purposes of construction, the line and grade was carried on wooden plugs, set in holes drilled in the roof, about 75 ft. apart.[1]

Nepean Tunnel, N. S. W.—This tunnel forms part of the water system of Sydney. It is 23,507 ft. (4.45 miles) long and has an inside width of 9 ft. 6 in. and a height of 7 ft. 6 in. It was driven from the two portals and six shafts, see profile, Fig. 151.[1]

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[1] *Eng. News*, June 11, 1903, Vol. XLIX p. 514.

The final survey for the line on surface was made with an 8-in. theodolite and hubs were set along the line at all important points. Permanent masonry observatories were built on the center-line on top of Wonson's Hill and on the east side of Cataract River, beyond the end of the tunnel. These two points nearly 4 miles apart were used to fix the positions of all subsequent monuments and of some of the shafts.

The observatory on Wonson's Hill commanded the whole line. Both observatories were protected by wooden houses which were provided with doors on the two sides that were on the line. A wooden screen was built about 50 ft. back of the Cataract River observatory and painted white so that a bar suspended over the center point would be clearly defined. The bar was held over the point by a wooden tripod. The center-line was also marked by a black streak 1 in. wide on a white ground on the top and one face of the Cataract River pier. This could be seen from Wonson's Hill. Outside of both the main observatories a semaphore was erected on a pole and fitted with cords and pulleys so it could be used to send signals.

The line through the observatories was then prolonged to the Nepean River portal by setting the instrument at Wonson's Hill, taking a backsight on the Cataract River observatory, lifting the telescope out of the wyes, reversing and pointing it to the Nepean River monument. A brass plate graduated for a length of 3 in. to 20ths of an inch was set in line on this monument and the graduation cut by the instrument sight was noted. The observations were repeated several times and the mean position was taken for the true point.

The best time of day for sighting was just before sunset in fine weather, but the calm nights were the best of all, as the instruments remained steady and the bars used for targets could be readily seen against screens of white cotton cloth that were illuminated from behind. The bars used for targets were of round steel 6 ft. long and $\frac{1}{4}$ to 1 in. in diameter. They were provided with 10- to 12-pound bobs which slid over them, to near their bottom and thus held them vertical. For the 4-mile sights, the 1-inch bars were used and the smaller ones were used for the shorter sights. At 1 mile, it was often possible to use a $\frac{1}{8}$-inch plumb-line.

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[1] Abstract of "The Alignment of the Nepean Tunnel, N. S. W.," by Thomas William Keele, *Proc. Inst. of C. E.* 1888, Vol. XCII, p. 259.

In order to carry the line down the shaft, a permanent line point was set in a masonry pier in the vicinity of each shaft from which the center-line was located. From this the line was marked on small piers, on each side of the shaft and about 50 ft. apart. Across these two piers, a fine steel wire was stretched and the plumbing wires were let down the shaft along side of this horizontal wire and about 12 ft. apart. The position of the plumbing wires was noted on scales at the bottom of the shaft, and a transit was set up in line with the two marks on the scales. The line through the transit was then transferred to spads driven into wooden plugs set in the roof, using plummet lamps for targets. When the tunnels had been driven over 1000 ft., brass scales were fixed in the crown of the tunnel and the plummet lamps attached to these. The shaft plumbing and tunnel alignment was repeated with great care so as to eliminate errors and detect possible movements of the survey points.

The elevation of a bench mark at the foot of each shaft was determined by connecting it by tapings with a bench mark on surface. Hooks were then set in plugs opposite each other on the side walls of the tunnel and at a uniform height of 2 ft. 9 in. above the grade. Strings stretched across the tunnel between any two pairs of hooks would then be the known distance of 2 ft. 9 in. above the tunnel grade and the foreman could sight across any pair of them and get a point in the heading at the known distance above the floor and so keep the grade.

The length of tunnel driven from each opening, and the results at the junctions are given on the next page.

When the tunnel was completed, daylight at one end could be seen clearly with the naked eye from the other end, a distance of $4\frac{1}{2}$ miles.

Name of heading	Length in feet	Date commenced	Date headings met	Errors	
				In line, inches	In grade, inches
Inlet	2054.0	June 10, '81	Aug. 16, '84	3	$\frac{9}{16}$
Shaft 5, W	1513.25	Feb. 23, '83			
Shaft 5, E	935.0	Feb. 23, '83	Jan. 25, '84	3	0
Shaft 4, W	1970.0	Jan. 13, '82			
Shaft 4, E	2468.0	Jan. 13, '82	June 28, '84	$\frac{3}{8}$	$\frac{1}{16}$
Shaft A, W	425.0	Jan. 26, '84			
Shaft A, E	496.0	Jan. 26, '84	Aug. 11, '84	$\frac{3}{8}$	$\frac{1}{8}$
Shaft 3, W	1359.0	Jan. 29, '83			
Shaft 3, E	1323.42	Jan. 29, '83	July 28, '84	$\frac{5}{8}$	$\frac{1}{4}$
Shaft 2, W	3018.0	Nov. 18, '81			
Shaft 2, E	2385.0	Nov. 25, '81	Aug. 11, '84	$\frac{3}{8}$	$\frac{1}{4}$
Shaft 1, W	2286.0	Sep. 5, '81			
Shaft 1, E	1126.58	Sep. 5, '81	Sep. 23, '82	$2\frac{3}{4}$	$\frac{1}{10}$
Outlet	2148.0	Feb. 9, '80			
Total	23,507.25				

Gunnison Tunnel.[1]—This tunnel forms part of an irrigation project to carry water from the Gunnison River to Uncompahgre Valley and was completed in 1909. It is near Montrose, Colo. It is 30,582 ft. long, was driven 12 by 12 ft., and its cross-section inside of the lining is 122 sq. ft.

The country between portals is mountainous and rises from 2000 to 2500 ft. above the tunnel. It was first surveyed topographically and the terminals of the tunnel determined. These were then connected by a triangulation net and the azimuth of the tunnel calculated. A line was then run from the west-end point and closed on the east-end point within 3 in. This error was distributed and the line stakes were reset on the line. The surveying was done at night and checked on cloudy days, in the early morning or late afternoon, when the sun was not hot enough to affect the results.

One shaft 4980 ft. from the west portal was used in construction but as soon as this distance was holed through the tunnel alignment was carried in from the portal.

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[1] Abstract from *Eng. Rec.*, Aug. 28, 1909.

The lines of levels between ends were 10 miles long and had to climb 2100 ft. and 2600 ft. to get over the ridge. The levels were run by two different routes and rerun until they agreed closely.

The distance between ends was calculated from the triangulation net and was also measured direct. The latter was 3.16 ft. longer than the triangulated measurement. The errors at the meeting of the headings were: in alignment = 0.04 ft.; in elevation = 0.32 ft.; in distance = 0.86 ft. more than the triangulated distance.

Cincinnati Water Works Tunnel.[1]—This is a gravity tunnel $4\frac{1}{4}$ miles long to carry settled water to Cincinnati. It is 7 ft. inside diameter, has a grade of 1 in 2000, and is about 130 ft. below the surface. The line is broken by angles between tangents so as to keep it under the city streets as far as possible.

An accurate surface survey was necessary in order to determine the available route and to locate the shafts. The first three tangents in the city all contain obstructions which prevented clear sights and required ingenuity in passing. The others gave clear sights and a small river was crossed by triangulation. The distance was measured with a 50-ft. tape between stakes set 50 ft. apart or at changes in the slope and the length was marked on them. The elevations of these stakes were determined by leveling and the tapings were corrected for slope. The distances were all measured four times under different conditions. The tape was used at a constant pull of 14 lb., the temperature was noted and the distances were corrected for variations of the temperature from that at which the tape was standard. No difference greater than 1 in 30,000 was accepted, and the mean of all accepted distances was used. Angles were measured by repeating ten times by three or more observers and the averages of all observations were used.

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[1] Abstract from "Gravity Tunnel for the New Water Works of Cincinnati," by J. A. Hiller, *Eng. Rec.*, March 4, 1905, Vol. LI, p. 232.

An observation station was located at each shaft and a line target was set at or near the distant angle point. If the shaft was at an angle, a station was erected on each tangent. The observing platform was built independent of the instrument support, and the whole was housed in as a protection from sun and wind.

The plumbing-wires were No. 25 piano wire (about $\frac{1}{60}$ in. diameter), hung from movable clamps, mounted on planks across the shaft, and stretched by 20-pound cylindrical lead weights. The weights hung in glass jars of glycerine and could be seen, thus insuring that they hung free at all times.

At the bottom, the jar nearest the transit was placed on a stand about 3 ft. from the floor, and the further one was set on the floor, so that either one could be observed independently of the other. A white screen was placed behind each wire and was illuminated by an electric lamp. Sights were taken directly on the wires.

When the transit was in line with the two wires, the direction was transferred to the vernier scales and their position read to $\frac{1}{100}$th of an inch. This was repeated a number of times with the telescope both normal and reversed. Several independent trials of the alignment were made and in all about 50 readings were made on each scale. The mean was used for the working position.

In the tunnel, the transit was set on a wooden strut placed across the tunnel at the spring line of the arch, the strut being held in place by large set screws, the clamp for the instrument had a traversing attachment by which it could be moved sidewise for a short distance. The cross-wires of the transit consisted of a diagonal cross and two vertical wires, so spaced as to include about $\frac{1}{16}$ in. at 60 ft., so when sighting on a plumb-wire, it appeared as a black line with a white line on each side and made the setting both accurate and easy. The line from the vernier scales was extended as the excavation advanced, using the necessary reversals of the transit to eliminate errors and setting line points on the mean of all the observations. The distances were measured along the roof, using the same precautions as on surface. Angles were repeated several times and later curves of 30-foot radii were laid out to ease off the intersections, but the deflections at the bends being small, little or no additional excavation was needed to enable the lining to be built on the curves. The levels were carried down the shafts by taping taking four to eight measurements at each shaft, and using the mean.

The following table shows the condition at the shafts and the accuracy of the junctions:

TUNNEL MEASUREMENTS; CINCINNATI WATER WORKS

Shaft	Heading	Distance between plumb-wires	Angles turned in each heading	Length driven	Error in alignment	Error in levels
No. 1	East	9 ft. 3 in.	0	478.3	$\frac{1}{16}$ in.	$\frac{1}{4}$ in.
No. 6	West	8 0	0	541.3		
No. 6	East	8 0	0	641.1	$\frac{7}{8}$ in.	$\frac{5}{8}$ in.
No. 2	West	6 0	2	3220.2		
No. 2	East	6 0	2	3443.0	$\frac{3}{8}$ in.	$1\frac{5}{8}$ in.
No. 3	West	8 0	0	2267.9		
No. 3	East	8 0	2	2686.7	$\frac{5}{16}$ in.	$1\frac{1}{4}$ in.
No. 4	West	6 6	0	2472.1		
No. 4	East	6 6	1	3507.1	$1\frac{1}{2}$ in.	$\frac{3}{4}$ in.
No. 5	West	9 3	0	3006.4		

SUBAQUEOUS TUNNELS

P. R. R. & L. I. R. R. System, New York City

In 1904, the Pennsylvania R. R. started to develop a station in New York City at 32nd St. and 7th Ave., in conjunction with the Long Island R. R. This necessitated the building of the tunnels shown in the profile, Fig. 152

Under the rivers the railroads run through single track circular tunnels lined with cast-iron plates coated on the inside with concrete. There are two of these tubes under the Hudson River and four under the East River. They were all driven through the silt and fine sand by means of compressed air and shields. The cast-iron lining was built inside the shield as fast as it was advanced. The tubes are 23 ft. outside and 21 ft. 2 in. inside diameter. The Hudson River tunnels are each 6550 ft. long between shafts and the East River ones are each about 3900 ft. long between their shore shafts.

From the Weehauken shaft at the west end of the Hudson River section, two tunnels 25 ft. 10 in. wide by 21 ft. 5 in. high were driven westward, largely in rock, under Bergen Hill and were brought to the surface on the Hackensack Meadows. Across New York City, two tunnels were driven in rock from several shafts, and connected the subaqueous tunnels under the two rivers. On Long Island, the tunnels were gradually brought to the surface, the deep portions near the river were driven by tunnel methods and the shallower parts were built by the cut and cover method.

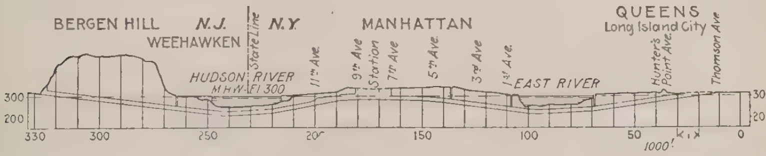

FIG. 152.—Profile of the tunnels of the P. R. R.-L. I. R. R. system, New York City.

Hudson River Tunnels.[1]—*The surface survey* was begun in November, 1901. Permanent monuments were set in prominent locations on both shores on the line of the tunnels and the distance across the river was obtained by triangulation. Base lines were established on each bank nearly at right angles to the line of the tunnel and about 6350 ft. apart. The Manhattan base line, about 2242 ft. long, lay along the west curb of 11th Ave., and its intersection with the tunnel center-line was taken as station 200, with the station numbers progressing westward. The end points of these bases and several auxiliary points on each were taken as station points for triangulation. The base-lines were measured with a 100-foot steel tape, previously standardized. In use, it was supported every 20 ft., a tension of 12 lb. was applied by a weight working over a bicycle wheel, and the position of the forward end of each tape length was marked on the brass top of a small heavy trivet or spider set on the ground. The angles of the triangulation were read by repetition, using a large number of series, with different observers. The instrument was an engineer's transit with a 7-in. horizontal circle and reading to 10 seconds.

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[1] Abstract from "The Construction of the Pennsylvania R. R. Tunnels under the Hudson River at New York City," by James Forgie, *Eng. News*, Dec., 13, 1906, Vol. LVI, p. 603, and Feb. 28, 1907, Vol. LVII, p. 223.

The determination of levels on the two shores was made by tide gage comparisons and by direct leveling. Tide gages were set up on both sides and read at intervals of two minutes during slack water and of five minutes while the tide was running, for 31 days. From these readings the mean stage was computed, and this gave a datum common to both banks. The method of direct sighting involved the use of an instrument and a rod on either side, with equal lengths of sight across the river to eliminate the effects of curvature and refraction.

The shaft plumbing was done after the tunnels had been started in order to establish the center-lines in them.

At the Weehawken shaft, which was directly over the tunnels, brass plugs were set in the coping of the east and west walls of the shaft on the line of the north tunnel and from these by means of a trammel with a spread of 37 ft., similar plugs were set on the line of the south tunnel. Pairs of plumb-lines were lined in with these plugs and the center-lines transferred to permanent monuments set in the floor of the shaft, from which the survey lines in the tunnels were prolonged.

At the Manhattan end, the shaft was some distance to one side of the tunnels. A surface line at right angles to them was transferred down the shaft by two plumb-lines carrying 30-pound weights suspended in water. Underground, this line was prolonged to the tunnels, right angles were turned, and plugs were set in the rock floor to mark the tunnel lines. About 500 ft. of each tunnel was controlled from these plugs.

Just before the beginning of the shield work more precise determinations of the center-lines were made. Two 10-inch pipes were sunk from the surface to the rock, and 8-inch holes were drilled through them to the tunnel at points about 158½ ft. apart and on a line parallel to the axis of the north tunnel and 2.7 ft. south of the center-line of the north tunnel. Plumb-lines hung in these holes served to establish permanent marks in the rock floor of the tunnel, thus giving a base-line of 158½ ft. for prolonging a line about 3400 ft. long. The floor monuments consisted of iron bars 4 in. in diameter and 4 ft. long cemented in holes in the rock floor and having brass plugs 3 in. in diameter and 6 in. long set in their upper ends. The exact marking of the line point was done by drilling a small hole in the brass plug. The center-line of the south tunnel was marked by similar line points set, by trammels, from those in the north tunnel.

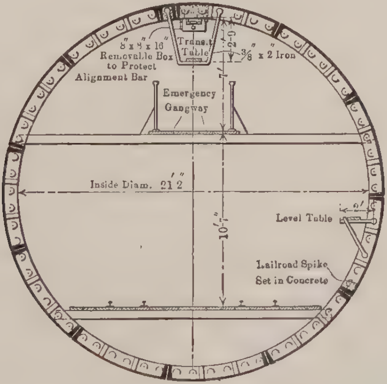

FIG. 153.—Cross-section of the Hudson River tunnel, showing the survey arrangements.

The alignment surveys in the tunnels were made on an auxiliary platform 7 ft. below the roof, and on a level with the emergency locks in the bulkheads, Fig. 153. At the Weehawken end, these locks were on the center-line but at the Manhattan end, the emergency locks were at one side, necessitating the running of the survey line a few feet off the center.

The transit was supported on an instrument table bolted to the top segments of the tunnel at intervals of 150 to 200 ft. These tables consisted of two stirrups of $\frac{3}{8}$ by 2-inch iron bolted to adjacent flanges of the lining and supporting a board on which the transit could be set on a trivet. They were prevented from vibrating in the longitudinal direction by a diagonal bar of iron in the plane of one pair of side bars, and connecting the bottom of one hanger with the top of the other, see Fig. 154.

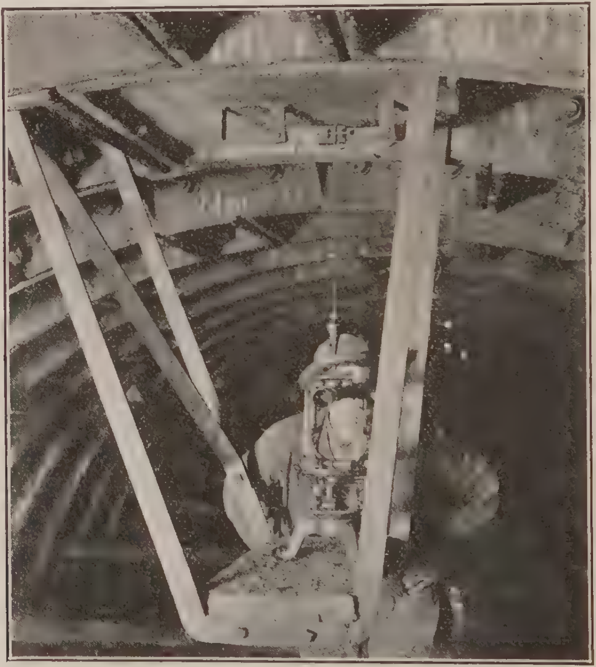

FIG. 154.—Station equipment, Hudson River tunnels.

Immediately above each table a station point was bolted or cemented to the roof plates. These station points were made so that a plumb-bob could be hung from them and moved sidewise until on the line of sight of the rear transit. When accurately set, the position of the bob was read from the scale and recorded.

The station points went through several changes in design. The first had a scale only 1 in. long but when the tunnel entered soft ground, it was found necessary to increase them to 3 in., see *A* in Fig. 155. The bob-cord was hung over the bar and moved by hand. The scale was graduated to $\frac{1}{50}$ in. Later, when the tubes had advanced some distance into the Hudson River silt, it was found that a still longer scale was desirable, as larger lateral motions of the tunnel occurred here and a 6-inch vernier scale was adopted as shown at *B*, which was used up to the completion of the work, and proved very satisfactory. This scale was graduated to $\frac{1}{100}$ ft. and could be read by the vernier to $\frac{1}{1000}$ ft. When not in use, the scale was protected by a padlocked box, attached to hasps set in the cement block.

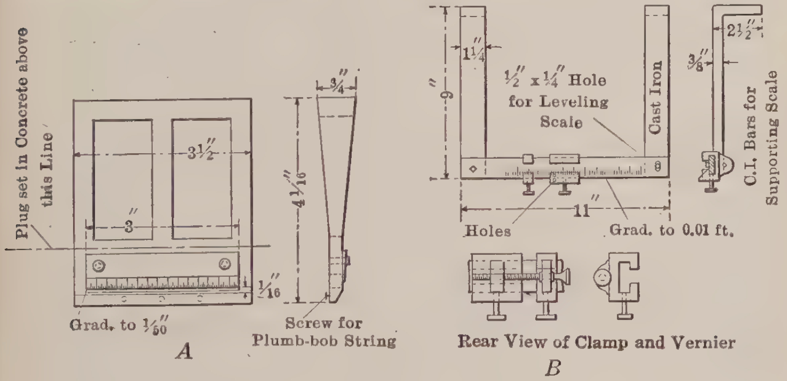
Plug set in Concrete above this Line
3½″
3″
¾″
4$\frac{1}{16}$″
$\frac{1}{16}$″
Grad. to $\frac{1}{50}$″
Screw for Plumb-bob String
A
1¼″
6″
½″ x ¼″ Hole for Leveling Scale
Cast Iron
⅜″
2½″
C.I. Bars for Supporting Scale
11″
Holes
Grad. to 0.01 ft.
Rear View of Clamp and Vernier
B

FIG. 155.—Alignment scales.

When sighting on a plumb-bob, a light-box was set behind the cord to make a white background for it. The first light-box had a sheet of tracing cloth stretched across its front and this was illuminated by incandescent lamps inside the box. This was superseded by a more efficient arrangement consisting of a box 20 in. square by 6 in. deep with two lamps on each side concealed behind boards, so placed as to partly close the front and still leave a vertical slot in the center through which the reflected light from the white enameled interior was seen. This design proved satisfactory except for very long sights and in foggy atmosphere where they were not bright enough and boxes with six and even eight 32-candle-power lamps had to be used.

The general scheme for the alignment surveys consisted of prolonging the line of the tunnel, from the permanent monuments in the rock section, through the emergency locks, to the last station point in the tunnel, which would be about 50 rings, that is 125 ft., behind the shield. Such lines were run at intervals of three to four months in the early stages of the construction but later at intervals of one month. Check lines were run at intervals of one or two weeks.

The transit work at any station for the line surveys was as follows: The transit was accurately set in the plane of the survey line; a backsight was taken on the preceding station point; the telescope was plunged; the plumb-bob, hung from the scale of the forward station point, was set in line and its position was read; the observations were then repeated with the telescope in the reversed position on the backsight; and the bob was reset, its position was read on the scale and the mean of the two readings was recorded. The difference between this reading and the last previous one on the same scale gave the amount that the tunnel had moved laterally in the intervening time. Leaving the plumb-bob in place where set, the transit was then carried forward and set accurately under the bob and the whole process repeated to set the next station. For the "precise" alignment work, each setting of the instrument or plumb-line was made to depend on a large number of independent settings taken with the telescope both normal and reversed.

The subaqueous tunnels were made as small as possible in order to reduce the cross-sectional area to a minimum and economize in the excavation. This small cross-section reduced the clearances so that it was necessary to keep the shield and the line of the tunnel close to the prescribed alignment.

One ½-degree horizontal curve occurred in the tunnels, with an intersection angle of 0°-53′-25″. The intersection point fell inside the tunnel; the instrument was set up on this point, and the new tangent was set out by turning the angle. The curve was laid out by offsets from the tangents.

In passing an air lock the transit was set up in the lock and the door through which the sight was being taken was opened while the other was shut, then closing the first door, and opening the second, the next sight was taken. As the repetition of backsight and foresight with a single observer would have required him to change from one pressure to the other for each pair of sights, the plan of using two observers was adopted. The first man, on the low-pressure side, took the backsight, then stepped out of the lock and closed the rear door, whereupon, the second man, on the high-pressure side, admitted compressed air to the lock, opened the inner door, stepped to the transit and set the forward plumb-line by the transit as pointed by the first man, he then closed the inner door, the first man released the air from the lock entered, repeated the back observation with the telescope reversed, stepped out of the lock, closed the rear door and left the second man to complete the pair of settings on the forward plumb-line.

For a long time, the fog in the tunnel was so troublesome that sights longer than 200 ft. were rarely possible and this distance was adopted as the distance between the alignment stations. Later a second bulkhead was put in the tunnel, halving the change in the pressure at each lock when the air became much clearer, sights 400 ft. long could be taken, and alternate stations were omitted in the prolongation of the precise line.

In the measurement of the distances, intermediate points were set in the tunnel roof between the precise line plugs and the measurements were made between plumb-lines suspended from these points and from the station points.

On the Manhattan side, the tape was suspended on the tunnel grade, was supported only at the ends, and was stretched by a tension of 20 lb. Several readings of each length were taken and their mean was corrected for temperature, sag, tape unit and grade.

On the Weehawken side, the measurements were taken horizontally; the tape was supported every 20 ft. by an adjustable hanger, and a tension of 12 lb. was applied. The measurements were only corrected for temperature and tape unit.

Each tunnel was stationed twice and where appreciable differences were found, a third measurement was made.

The levels on the Manhattan side were run from the transit tables, using as bench marks certain raised letters on particular segments of the cast-iron lining near the top. The elevation of the invert was found by taping the vertical diameter.

On the Weehawken side, the levels were run from level tables bracketed to the sides of the tunnel near the lower or working platform; the bench marks consisted of track spikes set in concrete in angles of the lining. This arrangement allowed the leveler to take the readings directly on a rod held on the roof and on the invert.

Levels were run from the rock section of the tunnels, each week, readings were taken on the front flange of every tenth ring, at both the invert and the roof. For ordinary levels Philadelphia rods 6, 13, and 16 ft. long and graduated to 0.01 ft., were used both with and without targets. For the precise levels, New York rods with targets and rod levels were used.

The horizontal diameter of the tunnel was taken and measurement of chords between specified bolt holes were made at these rings, to serve as a rough check on the distortion of the lining.

The shield checking was done by two corps, one employed at night and one during the day to check the position of the shield every few hours, so that any slight departure of the shield from its true course could be detected and it could be brought back to course at once.

At the meeting of the headings the two shields came together without apparent error. After they were removed, two precise checks on the alignment were made in each tunnel. The north tunnel survey lines were found to be 0.041 and 0.0585 ft. apart by the two determinations and the south tunnel survey lines were found to be 0.0013 and 0.0154 ft. apart. The Weehawken lines were to the south in all cases. A precise level check was run to the middle by both corps; they differed by 0.045 ft. in the north tunnel, and by 0.030 ft. in the south tunnel. The Manhattan levels being the higher in both cases. A line bar near the State line was tied in to the precise stationing of both corps and showed that the Weehawken stationing was greater in both tunnels; in the north one by 0.954 ft. and in the south one by 1.053 ft., that is the tunnels were about a foot shorter than calculated. Part of these errors in juncture were probably due to errors in the surface survey across the river.

East River Tunnels.[1]—In these tunnels, each bulkhead contained the usual locks for the passage of men and materials and in addition, it contained a special alignment lock, 15 in. in diameter and 20 ft. long, with its center 4 ft. above the tunnel floor. This alignment lock allowed the survey lines to be carried from the shaft into the tunnel without the necessity of setting up the transit in an air lock or interfering with the tunnel work. In each end of this lock, a transversely adjustable plumb-bob was hung. The door at the rear end of the lock was opened and both bobs were set on line by means of the transit which had previously been pointed on the line. The rear door was then shut and the inner one was opened permitting a transit on the pressure side of the lock to be lined in by sighting on the two plumb-bobs. This line was then prolonged through the tunnel. This method of passing the bulkheads was found to be very satisfactory.

The device for holding the bobs in the alignment lock consisted of a movable block which slid transversely on a smooth rod, placed across the tube, and was shifted by a screw passing through the side of the tube and ending in a thumb screw on the outside. The bob was hung from the block. The shifting apparatus was held by brass castings attached to the outside of the tube. The shifting screw was passed through a stuffing box, which was found to be necessary to prevent the escape of air which caused currents which affected the bob.

Inside the air lock, the alignment was marked at intervals of 200 ft. on brass scales attached to the lining, or by spads driven

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[1] Abstract from "East River Tunnels, P. N. Y. & L. I. R. R.," *Eng. Rec.*, July 28, 1906, Vol. LIV, p. 97.

into wooden wedges inserted in the caulking recesses between the rings. The position of each ring of the segmental lining was located and recorded by the surveyor as soon as it was completed, thus affording a constant check on the grade and alignment of the tunnels.

PROGRESS DIAGRAMS

In driving tunnels, the surveyor is required to keep track of the progress made with the work. This is conveniently done on a

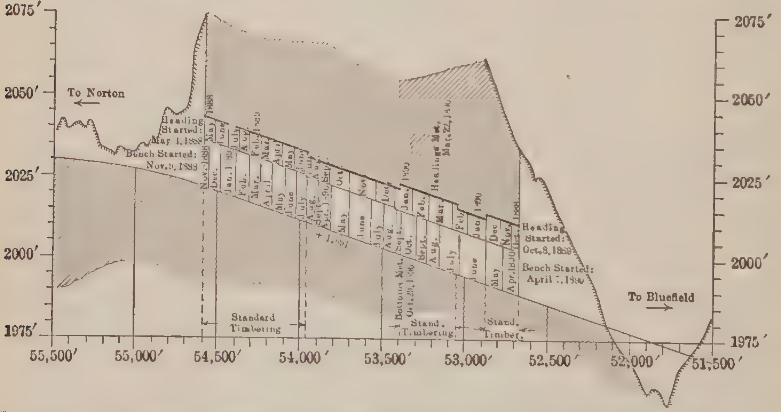

Fig. 156.—Progress diagram of the Little Tom tunnel, Norfolk & Western R. R.

"Progress Diagram" which shows at a glance the condition of the work at any time and the relative progress made.[1] Fig. 156 shows each month's progress on a tunnel 1925 ft. long, in Wise Co., Va., on the Norfolk & Western R. R. The headings were driven considerably in advance of the benches. The progress of the headings is given in the upper part and that of the bench in the lower part of the profile.

Where there are shafts, and work is carried on in both direc-

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[1] *Eng. News*, April 19, 1900, Vol. XLIII, 257.

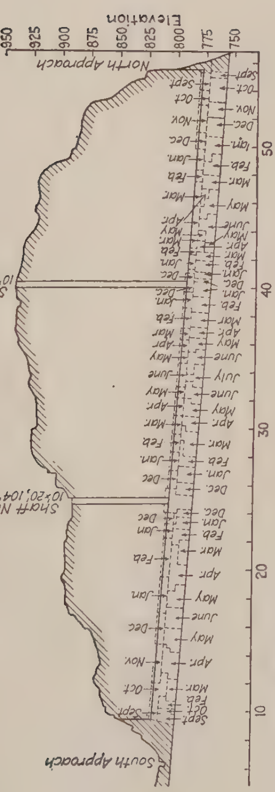

FIG. 157.—Progress diagram of the Scranton tunnel, Lackawanna & Wyoming Valley R. R.

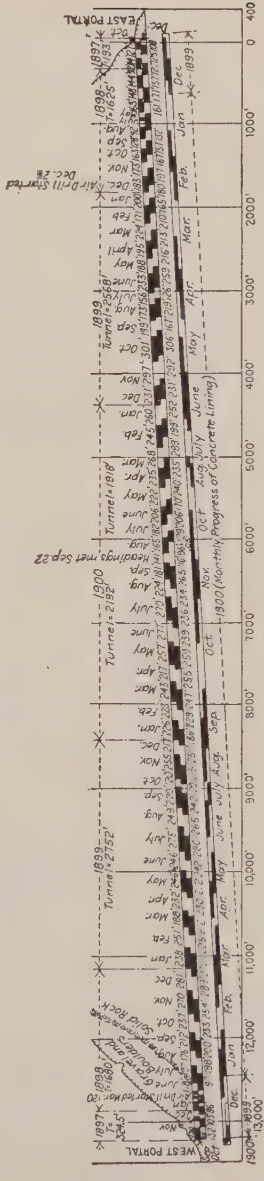

FIG. 158.—Progress diagram of the Cascade tunnel, Great Northern Ry.

tions from the bottom of them, the time involved in sinking the shaft is important, and there are more working places to be measured up and plotted. Such a case is shown in Fig. 157, which is the profile of an interurban electric railway near Scranton, Pa.[1] Here the headings were driven in advance of the benches.

On the Cascade Tunnel, on the Great Northern Ry., the headings and benches were driven together, and the progress diagram was kept in a different form, see Fig. 158. The lower part of the figure shows the record of the progress made in lining the tunnel with concrete.[2]

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[1] Geo. B. Francis and W. F. Dennis, *Trans. A. S. C. E.*, May, 1906, Vol. LVI, p. 219.

[2] *Eng. News*, Jan. 10, 1901. p. 25.

CHAPTER XIII

SURFACE AND MINE MODELS.

A model may be defined as a representation of the three dimensions of an object in relief while a map or drawing shows the object on a flat surface. Models are valuable in connection with mining to illustrate the character of a tract of land, the geological formation of a locality, or the workings of a mine. They give the information in such a way that it can be comprehended by persons unfamiliar with the locality, or who cannot read a map.

SURFACE MODELS.

Plaster Models.—The common form of surface models is the relief map, made to illustrate the topography. These are usually made of plaster of Paris, as it is easy to mold and easy to carve after it has hardened. They may be made by stretching a topographic map on the base board of the model and then driving finishing nails or pieces of wire vertically into the base so that their tops will come to the desired elevation of that part of the model. The model is then filled with plaster of Paris until the surface conforms with the tops of the wires; the minor variations are carved in the plaster after it has set, by comparing it with another copy of the topographic map. Flaws in the surface are filled up and the whole is painted with suitable colors. Details that do not affect the topography, as roads, etc., are simply painted on the surface.

Instead of pins, pieces of thin metal may be cut so that their tops represent the profile along a certain line and these being properly placed serve as guides in placing the mass of plaster, which is then carved for the details. Or, the contour map may be applied to a sheet of thin wood, and each contour followed with a jig saw; giving a saw cut along each contour line. Thin strips of metal corresponding to the height of the respective contours are then placed vertically in the saw cuts and serve as a guide for shaping the plaster, which is finished as before described.

Wooden Models.—Wood is lighter and stronger than plaster but it is not as easily worked into small details. This restricts the use of wood to topographic models of small tracts which are made to a large scale. Such models are often wanted of the surface of a mining property in order to show the boundary lines, improvements, outcrops or geological conditions, and to supplement other models, showing underground conditions.

Wooden models are made by cutting out a thin layer of wood to the form of each contour and then fastening them in their correct position on top of each other. The thickness of each layer should equal the distance between the adjacent contours, and they should be put together so that the bottom of the layer comes at the elevation represented by that contour. The model then represents the topography by a series of steps and by carving off the projecting corner of each layer, the model becomes a miniature of the ground. It can be further finished by filing and sand papering; the cracks can be filled with putty or filler and then it can be painted the same as the plaster models. A wood should be chosen which has a fine grain as bass, poplar, or beech, so that it will carve easily in all directions. The center of each of the layers may be cut away so as to lighten the model.

MINE MODELS

Plate Models.—When several veins over-lie each other, or a deposit is worked in levels, it is common to plot each of these veins or levels on a separate sheet of tracing cloth and study them by laying one over the other. It is a short step from this to the plotting of each level on a separate plate of glass, and mounting them at the proper distances apart in a skeleton frame, Fig. 159.[1]

[1] From "Glass Models" by F. M. Kurie, *Mine and Min.*, Feb., 1904.

The top plate is made to represent the surface and shows the property lines, topographic features and roads. Each plate of the model is ruled with coordinate lines, so that it can be easily oriented when laid over the maps to have the workings plotted on it, or when set up in the frame. The map should be plotted on the underside of the glass so that the plates can be dusted off without rubbing the drawing. This requires the map to be drawn on the glass, in the reversed position, which can be done by laying the glass plate with the map-side up, over a tracing of

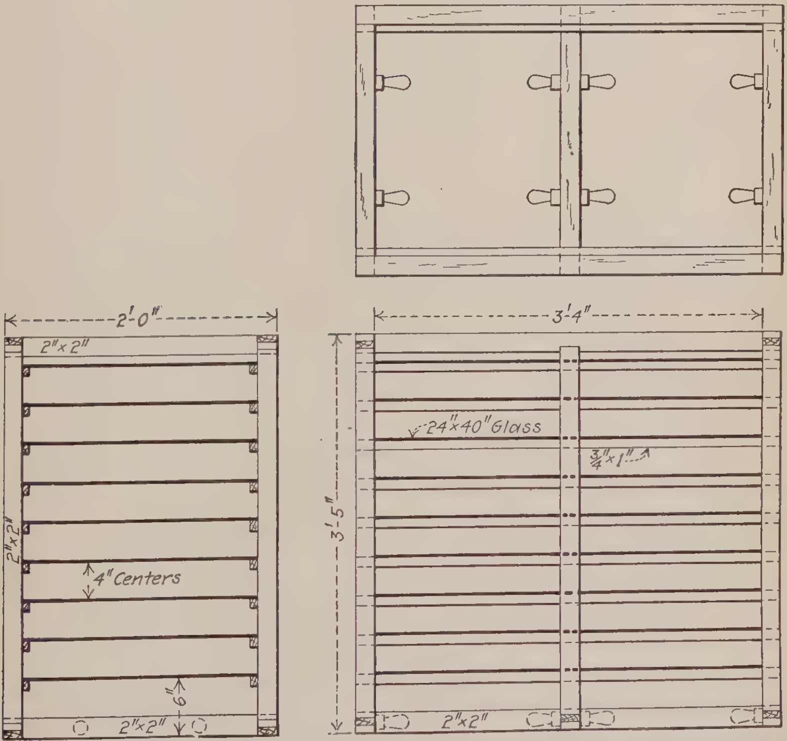

FIG. 159.—Glass plate model; dimensions will vary to suit requirements.

the mine map which has been turned face downward, thus giving a reversed map as viewed through the glass.

In the simplest form, the frame for holding the plates may consist of four corner posts connected by slats on which the plates rest; the posts should be far enough apart to allow the plates to be drawn out in at least one direction for alteration or study. The plates may be illuminated from below by electric lamps. Sometimes vertical cross-sections are drawn on vertical plates and these are mounted in a frame adjoining the horizontal plates, so that the workings on the vertical plates are projections of those on the horizontal. The more elaborate models have metal frames and are enclosed in glass cases to protect them from dust, but that can be opened for studying the model; the plates are often mounted in metal frames to facilitate the handling of them.

Drawing on glass, including the freehand work and lettering, has to be done with a ruling pen and it is difficult to make the ink or color flow or stick on plain glass. This can be overcome by using colors mixed with a varnish body; these will stick to the glass but are troublesome to handle in the pen. Small glass models can be made by coating the plates with gelatine which can then be drawn on with an ordinary drawing pen or a common writing pen using drawing ink. A photographic plate that has not been developed can be soaked in hypo to remove the silver coating, be thoroughly washed and dried, and will then be in a condition to take a drawing. Plates that are coated with gelatine are not quite clear. The coating is barely noticeable on one plate, but is cloudy enough to be objectionable if several are superimposed. A gelatine coating is easy to draw on, but corrections or alterations cannot be made without injuring the coating, hence its use necessitates careful work.

A model of the Montana-Tonopah mine workings[1] was made with glass plates, 24 by 42 in. of double thick glass, that were picked out so as to be as free from bubbles and imperfections as possible. The base was made of 2-inch pine, pinned and glued together; the back and one end were made of 1-inch pine and were 18 in. high; at the front corner was a post 1½ in. square, which was connected with the back and end boards by a top rail 1 in. square. The back and end boards and the corner post were grooved horizontally to hold the glass plates at a distance apart corresponding to the distance between levels. In addition, strips of galvanized iron ½ in. wide, bent to form ¼ by ¼-inch angles, were fastened between the front post and the back on a level with the grooves so as to support the glass plates at the end, it being found that the plates cracked at the corners due to insufficient support when used without these angles. The open sides were closed with ½-inch wooden doors which fitted over pegs in the base and hooked to a ½-inch top cover. The case could be locked if desired. The whole case was painted with dull white paint. The plates were illuminated by eight 1-candle-power electric lamps with frosted globes, set in the base. Mr. North has suggested that an improvement would be made in the model by making the bottom plate of ground glass to still further diffuse the light.

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[1] Abstract of "Glass Mine Models," by Edmund D. North, *Trans. A. I. M. E.*, Vol. XL, p. 755.

Vertical strips of glass 24 in. long and cut to a width equal to the distance between sheets were placed at intervals between the plates and had vertical sections drawn on them. These fitted into vertical grooves in the back board and were held at the front by U-shaped clips of brass spring wire pushed over the front edge of the horizontal plate, one on each side of the vertical strip. These vertical strips served to stiffen the horizontal plates and keep them from sagging and so were used from the bottom up even when there were no sections to be drawn on them. The sections and plates were all numbered so that it was easy to take the model apart to make additions of new material and to put it together again in proper order.

A scale of 40 ft. to 1 in. was used for the model. The outlines of the workings were drawn with a drawing pen and when dry, which took about 24 hours, the spaces between them were filled in with a brush, using the same color. A different color was used for each level. Windsor & Newton's oil colors were used for drawing on the glass; an equal mixture of turpentine and white japan was made up in stock and this was thoroughly mixed with the oil color in a small dish for use as needed. The different colors required different amounts of this mixture added to them; the proper mixture for each color being obtained when it flowed freely from a ruling pen on to the glass, and still was thick enough to stand permanently on the glass and not spread. Freehand lines and lettering were done with the ruling pen, as it gave a uniform width to the lines.

In making sections, everything within 10 ft. of the plane of the section was drawn in full lines, and more distant objects that it was desired to show were projected on to the section and drawn in dotted lines.

In the model of the Waihi gold mine,[1] in New Zealand, the vertical features were shown on gelatine instead of glass. This gelatine comes in thin sheets and can be easily cut with scissors and by heating a little can be bent into various shapes. The strips were placed between the horizontal glass plates on the slope of the foot wall, twisted to represent the warped surfaces when necessary, and held in place by brackets of the same material which were glued to both the glass and the foot wall piece. The foot wall strips had the stopes drawn on them from time to time so that they showed the progress of the work. Artist's oil colors thinned with a little turpentine and having a little drier added were used in a drawing pen. The slope of the surface was shown by strips of gelatine set vertically, and radiating in all directions from the highest point, the tops of the strips being cut to the profile on that line. The glass plates were 24 by 40 in. and $\frac{1}{4}$ in. thick so they did not need the support obtained in the previous case by the vertical glass strips. This model was a combination of glass plates and the skeleton type.

Skeleton Models.—The mine workings in a skeleton model are represented by solid material and stand out in space as if the surrounding rock had been removed. The levels or gangways are pieces of rectangular section bent to the proper shape, and are supported from a base so as to stand in their proper relation to one another. The shafts, inclines, and winzes are represented by rectangular strips, connecting the levels. The workings are sometimes made of wood and sometimes of soft metal of proper cross-section. Wood is light, but can only be fastened together by glue and drops apart as the latter dries out. The stopes are sometimes shown connected with the drifts and in other cases only the drifts are shown and the imagination has to supply the rest of the workings. Sometimes the vein is indicated by weaving strings in between the various levels or by bending a piece of wire cloth into the plane of the vein and extending from level to level.

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[1] Abstract of discussion by A. Scott Reid, *Trans. A. I. M. E.*, Vol. XL, p. 913.

Soft metal like lead can be soldered or bent and makes a strong model, but if it is solid in cross-section, it is heavy and requires thorough supporting or it will bend of its own weight. By using thin brass bent into the proper trough-shaped section for the levels, a light and strong model is obtained and the material is easily bent and soldered.

The skeleton models show the mine workings, which are holes in the ground, as solid pieces, while the solid portions of the vein and the surrounding country rock is represented by open spaces, but the observer does not have any difficulty in understanding the conditions because of this reversal and they are the best models yet devised to show all the conditions at a glance. The props needed to support the levels tend to confuse the model and make it unsightly. The models are complicated and require skill and ingenuity in working material, combined with a knowledge of mapping, in order to make them.

A model of the *North Star Mine* at Grass Valley, Cal., made about 1896, is shown in Fig. 160 and 161, and clearly illustrates the method of making this type of model. A plan of the mine is mounted on the base; the model is built immediately above it, being supported by the round white spindles and the surface is represented by a wire screen of about 10-mesh, bent to the form of the ground. Buildings on the surface are carved to scale out of wood and the little dump piles are made of fine rock mixed with

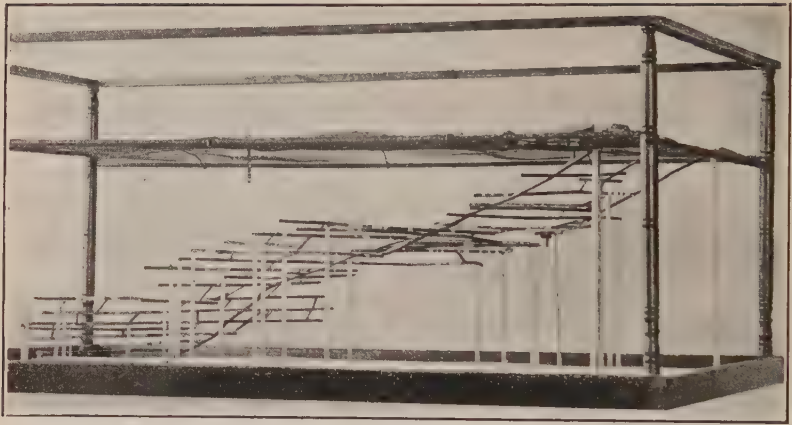

FIG. 160.—Skeleton model, North Star Mine, Grass Valley, Cal. Side view.

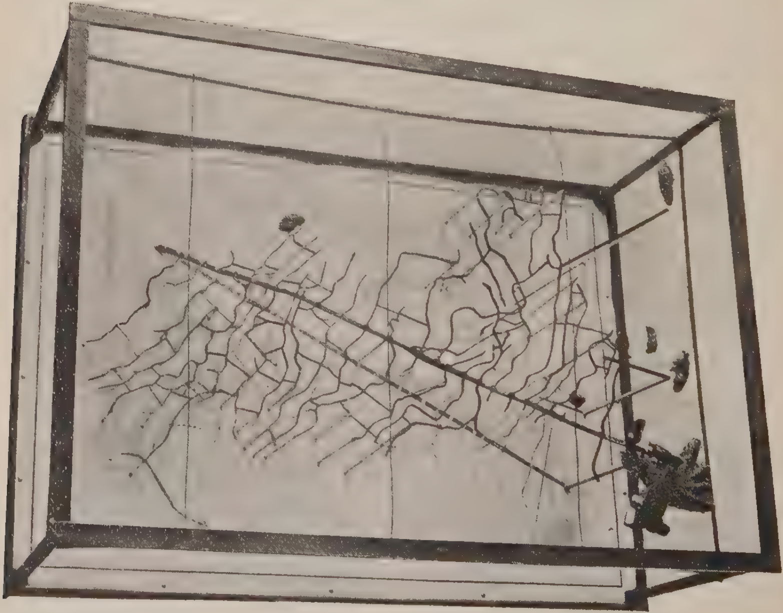

FIG. 161.—Skeleton model, North Star Mine, Grass Valley, Cal. Top view.

glue. The use of the screen to represent the surface is very realistic as may be seen in the side view of the model. The screen is also transparent and does not interfere with the inspection of the model below, as may be seen from the top view, where the workings have been photographed through the top screen. The screen is supported by several stiff cross-wires, bent to the proper profile. This model is to the scale of 1 in. = 50 ft. The levels are made of wood, $\frac{3}{16}$ in. thick and were cut to shape with a scroll saw. The levels are painted with different colors corresponding to the color system used on the map.

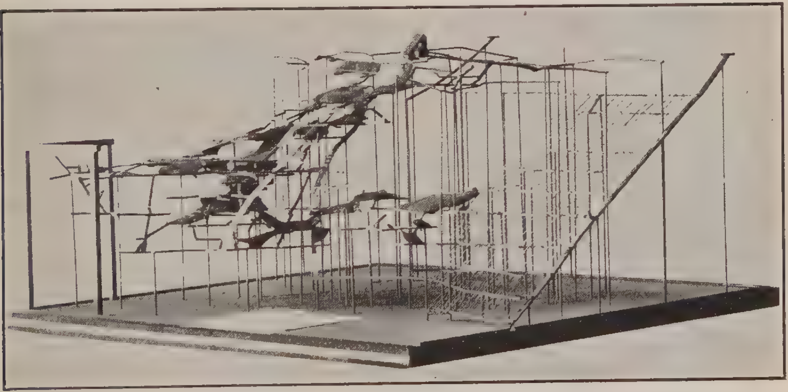

Fig. 162.—Skeleton model, Pennsylvania Mine, Grass Valley, Cal. W. Y. O. D. vein is shown by strings at right.

The model of the *Pennsylvania Mine*, at Grass Valley, Cal., made about 1900, is shown in Fig. 162. The stopes in this model are represented by carved blocks of wood glued to the proper levels. At the right-hand side of the figure is a neighboring mine, with its inclined shaft and levels and with the plane of its vein represented by a system of cords.

A model of the *W. Y. O. D. Mine* is shown in Fig. 163. In this the parts of the vein that have been stoped are indicated by pieces of wood attached to the levels and extending to the limits of the excavation. The unstoped parts of the vein are shown by strings. The inclined shaft is shown at the right side.

This mine adjoins the Pennsylvania Mine and is indicated by the strings at the right side of the model shown in Fig. 162.

The model used by the *Bunker Hill & Sullivan M. & C. Co.* in a law suit, called the Stemwinder Case, is shown in Fig. 164.

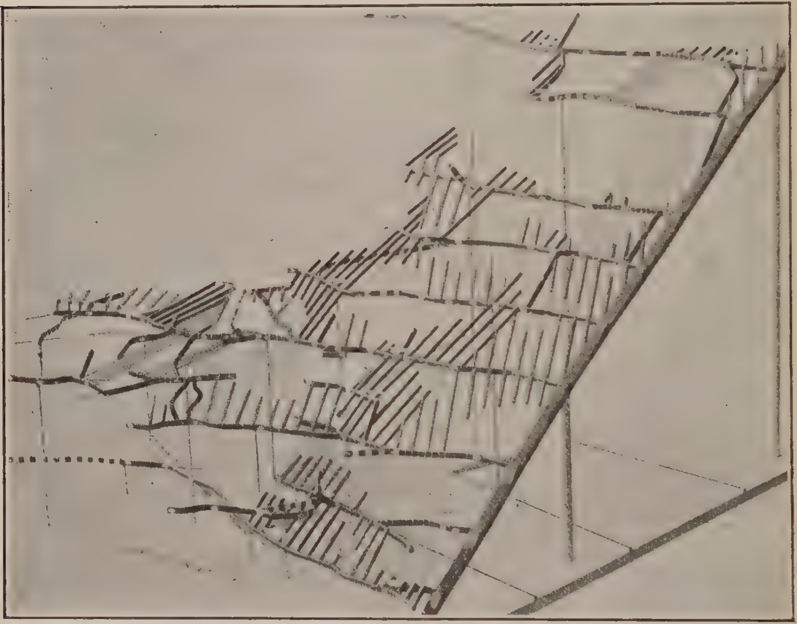

FIG. 163.—Skeleton model, W. Y. O. D. Mine, Grass Valley, Cal.

It was made about 1902. This model is made entirely of metal. The upper screen represents the surface and has the property lines painted on it. The under screen represents the foot wall of the vein. Both screens are held in shape by rods bent to the proper form. The levels and inclines are made of strips of sheet lead of approximately rectangular cross-section. The stopes are indicated by additional pieces of screen cut to the proper shape and held in position with fine wire. The stope screens are painted so as to emphasize them.

Other skeleton models (at California State Mining Bureau) have the levels and stopes made of brass castings soldered together. The models are complicated and the parts appear fragile, but owing to the strength of the metal, it is very rigid. The surface in this model is represented by $\frac{1}{8}$ in. diameter wires bent to correspond to the contours and these are held in position by other heavier wires which represented the lines of the claims.

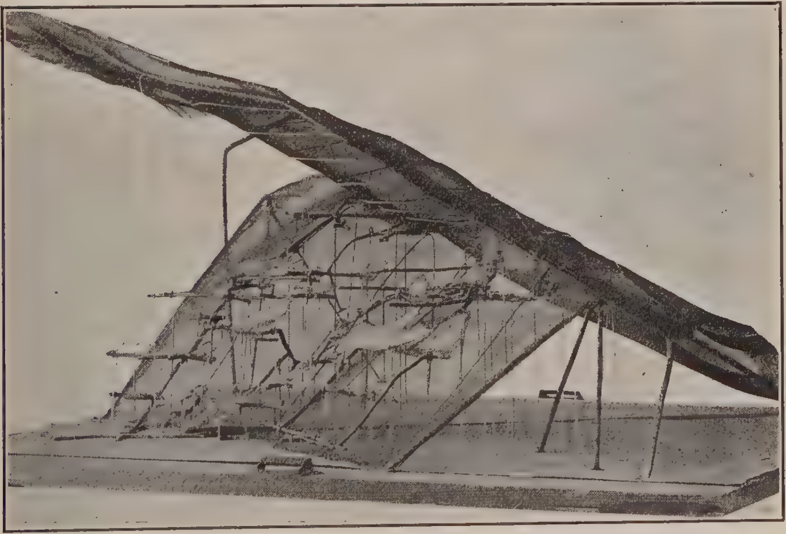

FIG. 164.—Skeleton model, Stemwinder Mine, Wardner, Idaho.

A model at the University of California is made with round brass wire about $\frac{1}{8}$ in. in diameter to represent the levels. This is not as true to the form of the mine as having them rectangular, but it is not a serious objection. The junctions are neatly made by soldering and the whole is so strong that it needs very few supports.

Block Models.—These consist of solid blocks carved to the shape of the ore body, or painted to represent the conditions, see Fig. 165. If the deposit is in a mass or pod, and has been worked in floors, the surveys of these floors will give a series of horizontal sections through the deposit. These plans can be laid on boards and cut out with a scroll saw. If the thickness of the board in each case is proportional to the distance between floors and the boards are properly oriented when piled one above another, then one side of each layer represents a horizontal section of the mine at that elevation, and the whole is a rough model of the deposit.

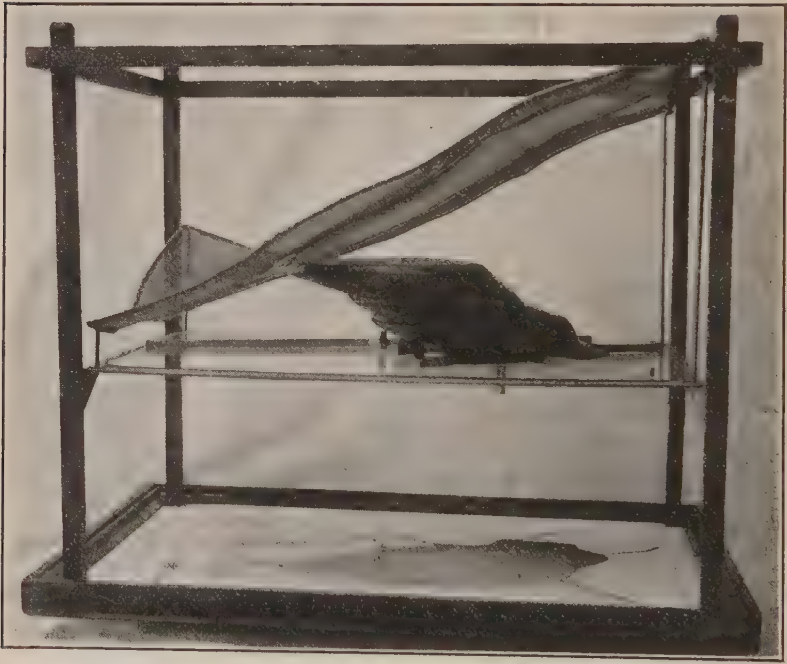

Fig. 165—Block model of a lenticular ore deposit.

The model may be finished by carving or filing off the projecting corners, filling the hollows with putty or plaster and finally sandpapering and painting. The method of constructing a block model of a deposit is identical with that for making a surface model or relief map. A carefully made block model is a very satisfactory miniature of the mass. It may be duplicated

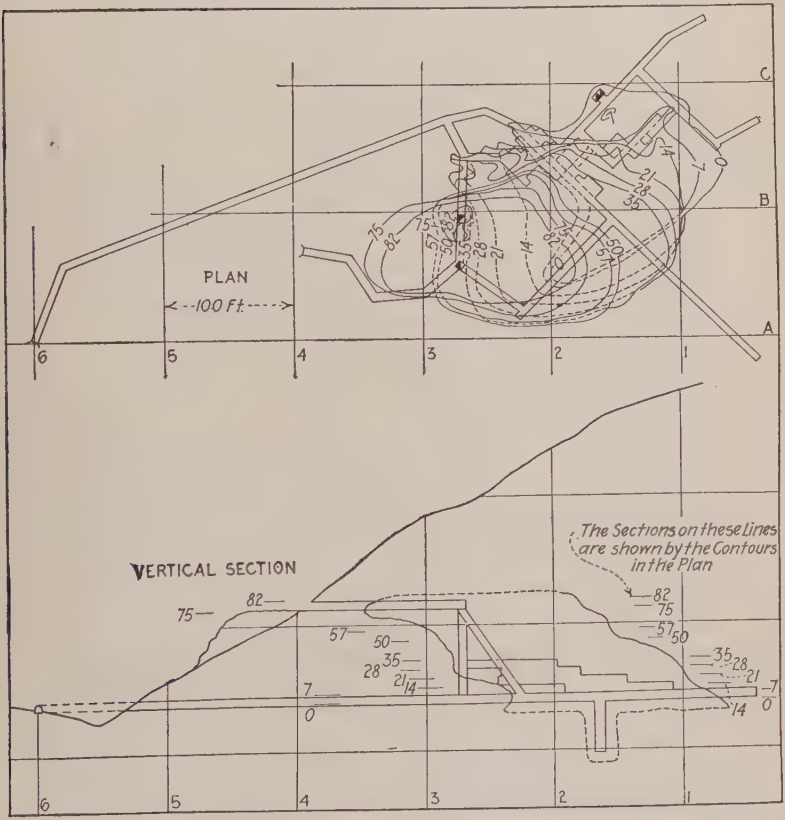
PLAN
100 Ft.
A
B
C
6
5
4
3
2
1
VERTICAL SECTION
The Sections on these Lines are shown by the Contours in the Plan
82
75
57
50
35
28
21
14
7
0

FIG. 166.—Plan and section of a lenticular ore deposit.

by using the original as a pattern and making a plaster mold from it, in which any number of copies can be cast in plaster, after coating the interior of the mold with shellac, varnish, or paraffine to prevent the casting from sticking.

The usefulness of a block model may be increased by making the layers of which it is made proportional to the distance between the working floors in the mine and then plotting the shape of the workings on the top and bottom surfaces of these layers.[1] The layers are oriented by means of dowel pins and may be separated for inspection or to record the progress made in the mining. Fig. 166 shows the plan and section of the lenticular ore deposit with the contours of both the top and bottom surfaces as worked out from a geological examination, from which the model, Fig. 165,

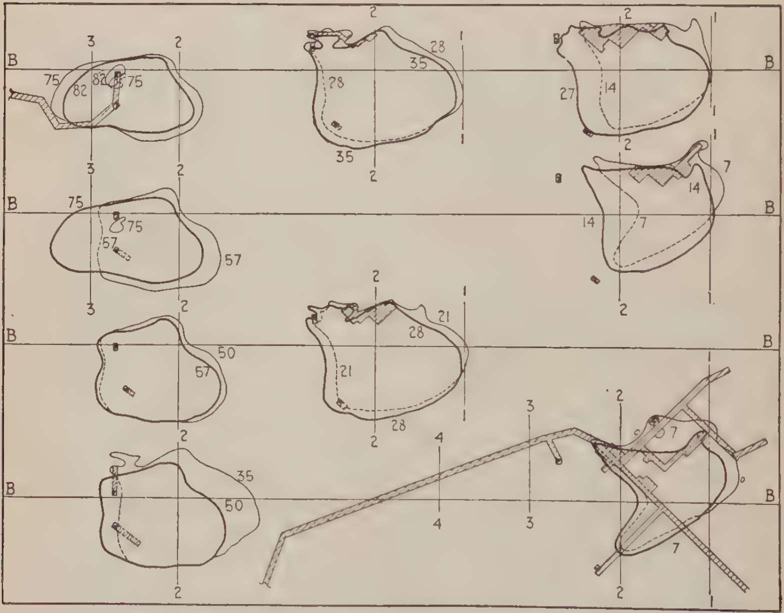

FIG. 167.—Block model, dissected, showing the workings plotted on the layers.

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[1] This improvement of the block model was developed by Lester C. Uren, when a student in the College of Mining, at the University of California, and the illustrations here shown are taken from his graduation thesis on "Mine Maps and Models."

was made, and Fig. 167 shows the top view of the various layers of the model with the workings plotted on them.

The block model becomes more realistic if the material in the layers is carved out as the ore is removed from the mine, instead of merely plotting the workings on the surface of the layers. In mines where the distance between floors is so great that most of the stoping is done in the body of the layers and would not show on their top or bottom surfaces, the layers have to be subdivided by arbitrary planes, some horizontal and some vertical, so as to expose the workings. Block models are the easiest form to make and they are the most natural as they represent solid ground by solid material, and workings by spaces, but they have to be inspected piece by piece. They are, however, valuable aids in studying the conditions in a mine and in planning out new work. They also enable men who have not had a surveyor's training to get correct ideas of the relation of one part of a mine to another, and to correctly interpret the influence of geological conditions.

The *Alaska-Treadwell Mine,* Douglas Island, Alaska, devised a model[1] of their mine of the block type with carved out working. The principle on which the model was constructed is shown in Fig. 168. A pile of blocks was made to represent the country in the vicinity of the mine at a scale of 25 ft. to an inch. The ore deposit was painted on these in white, the country rock was painted in black, and the excavations were carved out of the block from the result of the surveys. The new work was added monthly, from the surveyor's reports.

The blocks were rectangular in cross-section and long enough to reach across the deposit, being 4 by 4.4 by 48 in. and represented 100 ft. horizontally by 110 ft. vertically which was the distance between the levels. Parallel lines were drawn 4 in. apart across the block. The spaces and blocks were lettered and numbered as shown so that any block could be referred to and its position in the pile could be determined. Cubical blocks were tried

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[1] Abstract of "Mine Models," by E. F. Sheffield, *Univ. of Calif. Jour. of Technology,* April, 1904.

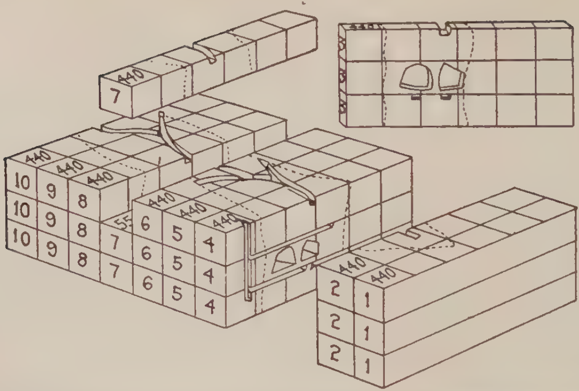

FIG. 168.—Construction of the block model of the Alaska-Treadwell Mine.

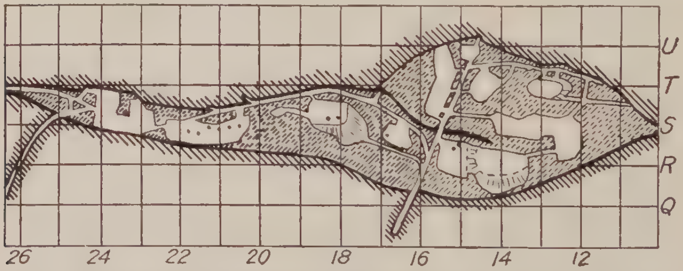

FIG. 169.—Alaska-Treadwell block model, showing the 100-foot. level.

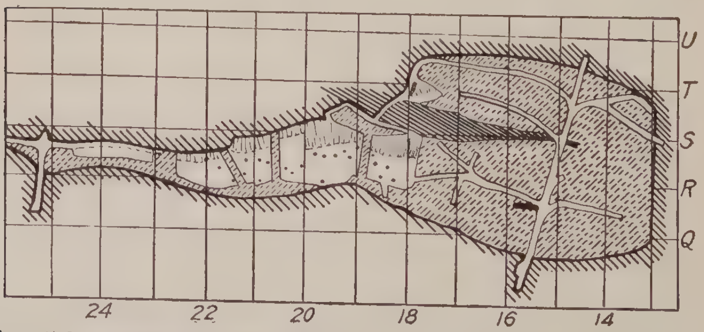

FIG. 170—Alaska-Treadwell block model, showing the 330-foot. level.

at first but the model was very puzzling to put together after having been separated.

The drifts are cut in the tops of the blocks so as to show when the upper blocks are removed. Fig. 169 shows a top view of the model with the blocks removed down to the 110-foot level; the unshaded portions are the workings and the large areas to the right of the main drift are the bottoms of the open cut or "Glory Hole" carved out of the blocks and the round spots are gimlet holes to represent chutes into the 220-foot level. Fig. 170 shows the blocks removed down to the 330-foot level, exposing the large stope to the left of the main drift; the three partitions across the stope are pillars of ore left in the mine.

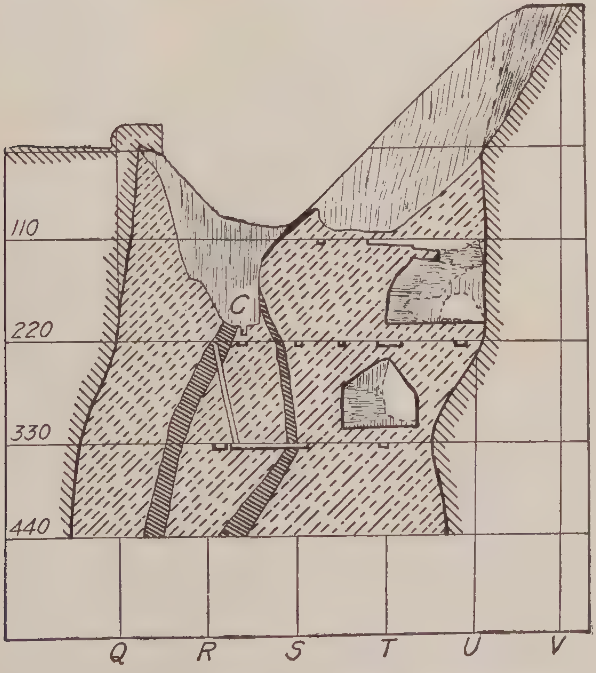

Fig. 171.—Alaska-Treadwell block model, showing section 15.

Figs. 171, 172 and 173 show the blocks removed so as to expose vertical sections on lines numbers 15, 16, and 18. In Fig. 171, a chute from the bottom of the open pit to the 220-foot level is shown at c, chiselled out as it occurs at the section; the mass of slate that has slipped off the wall to the right and mixed with the ore is shown; the stope on the 220-foot level had a flat roof and caved indicating to the mine foreman the need of arching.

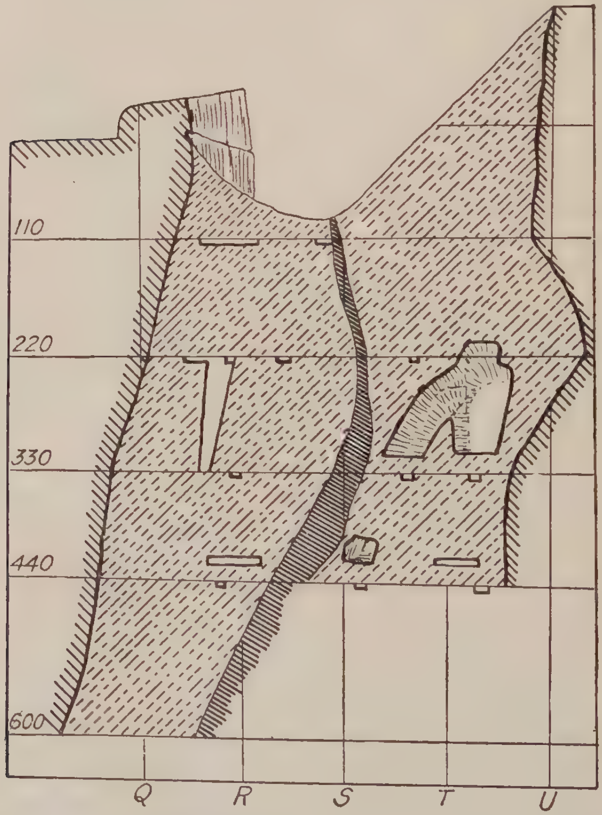

Fig. 172.—Alaska-Treadwell block model, showing section 16.

In Fig. 172, the progress of several stopes on the 440-foot level is shown, and the large stope on the 330-foot level is shown to be above the 220-foot level. In Fig. 173, the pillars across the stopes are shown with the drifts leading to the manways located in them.

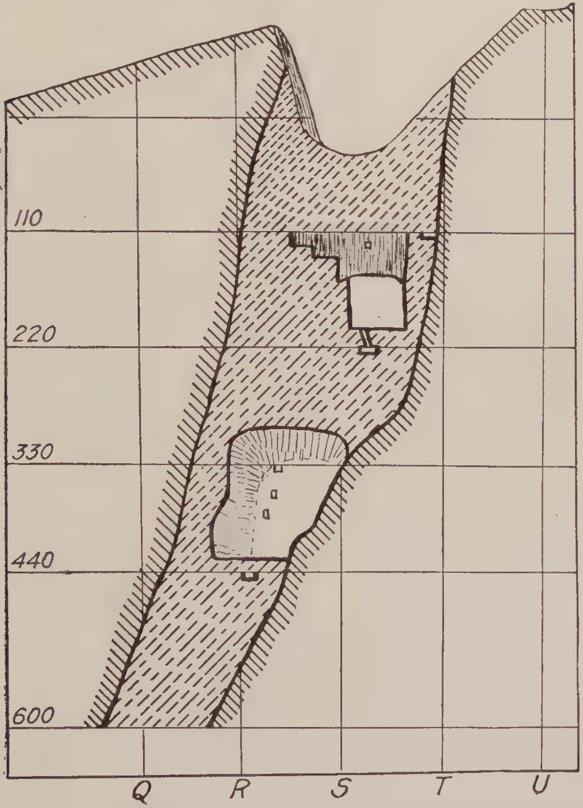

FIG. 173.—Alaska-Treadwell block model, showing section 18.

CHAPTER XIV

EXPLORATORY SURVEYS

Before mining can be done, the ore must be found. In unworked sections, the region that is supposed to contain mineral is searched in detail for indications of ore and these are followed by driving tunnels, sinking shafts, or boring holes to expose the ore; this is called *prospecting*. In mines, it is necessary to outline an ore supply ahead of the work in order to maintain a continuous output from the mine; this is generally done by driving drifts and shafts, and is called *development work*.

Both prospecting and developing are expensive, and need all the help that it is possible to derive from a study of the geological formation in order to locate the probable position of the ore and so reduce the amount of excavation to a minimum.

SURFACE GEOLOGY

The study of the geology, to be of value, requires that the data shall have been obtained by actual survey. The most satisfactory process is to use a topographic map for a foundation and to add the geology to it.

It is a convenience to have a separate squad to collect the geological notes after the mapping is done, then they can devote all their attention to the study of the geology and follow any line that is promising without being hampered with the surveying.

The geological features that are exposed on the surface are referred to as the *areal geology* of a region. A map of these features would have the areas occupied by each kind of rock indicated on it by tinting or by conventional hatching, with notes or signs showing the dip and strike of the rocks at the exposures, and would show the position, direction and dip of dikes and faults.

The maps of the areal geology give many indications as to the geological conditions below the surface, and taken with the information obtained from borings or mining, enable the stratigraphy of the region to be drawn.

U. S. Geological Surveys.—The system used by the U. S. Geological Survey consists of making:[1]

1. A primary triangulation,
2. Primary traverses,
3. Accurate spirit levels,
4. Secondary traverses,

and the collection of:

5. Topographic notes,
6. Geological notes.

The primary triangulation is made with a micrometer theodolite; the angles are read on five different parts of the circle and errors of closure of any angle is limited to 5 seconds. The stations are marked by iron posts, or by copper plugs or bronze tablets cemented into the top of stone monuments. The ends of base lines are similarly marked. The signals are preferably of sawed lumber, and are set over the station marks.

Observations for azimuth are made on Polaris on two different nights at each of two or more stations in each general locality, and each observation consists of six or more readings of the angle between the star and an illuminated mark placed at least one mile away.

Prominent points that may be of use to the topographer, or for future survey stations are located and the position of important features, as county court houses, section and county corners and state line marks, are determined.

The primary traverses are run with a transit reading to 20 or 30 sec. and a steel tape. The angles are repeated and are not accepted until two readings made on different parts of the circle agree within one minute. Flag poles are used as signals.

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[1] Abstract of "Instructions relating to the work of the U. S. Geological Survey to take effect May 1, 1903," published by the U. S. Geol. Surv., Washington, D. C.

The distances are measured with the 300-foot tape stretched with a tension of 20 lb. as shown by a spring balance, between tacks in stakes, set in line and at such distances apart that the measurements can be made horizontally, using a plumb-bob to bring the tape mark over the stake at the down-hill ends on the slopes. The temperature is noted every hour. The distance between stations is limited by the distance at which the flag poles can be seen.

Observations for azimuth are made at the close of each day's work and azimuth stations on long tangents are established at distances not more than 10 miles apart. The observations consist of three direct and three reversed readings of the angle between Polaris and an azimuth mark, and is preferably made near elongation. The watch used for determining the time of the observation must be compared at frequent intervals with standard time so that the error in the time of any observation will not exceed 10 seconds. On very crooked lines, the azimuth is determined twice daily by solar observations as a check on the angle work, in addition to the regular Polaris observations.

Two prominent marks, either copper bolts or standard bronze tablets, at least 500 ft. apart, are left at the beginning and end of each line and also at prominent points, as starting lines for other primary traverses.

Accurate spirit levels are run in connection with the primary traverses with Y-levels. The fore- and backsights are made of equal length, as found by pacing, and not over 300 ft. long, except where absolutely necessary as in river crossing. The sights are taken on the target; the rod is plumbed with a rod level and the rodman and the levelman keep independent sets of notes and each makes all the computations. As the rodman and levelman pass, the latter reads and records the target, and the entries and resulting calculations are compared.

Lines of levels are run in circuits so as to check back on themselves, but where this cannot be done, the target is set twice on each sight, and if the two settings do not agree within 0.002 ft. the sights are repeated. The rodman uses the first reading and the levelman the last reading in his notes. On closed circuits, the error in closing, in feet, should not exceed $0.05\sqrt{\text{distance in miles}}$.

The turning points are taken on conical steel pegs, 6 to 12 in. long with round heads, carried for the purpose, and driven in the ground.

Permanent bench marks are established in every township and at prominent places where they will be of value for reference; these are bronze or aluminum tablets cemented to permanent masonry structures, or bronze-capped iron posts set so as to project a foot above the ground.

A temporary bench mark is also set for every mile run; these are usually near road corners, where they will be convenient for connecting other lines of levels, and may be cross-marks cut in the solid rock or a nail driven in a knuckle cut in the root of a tree, or any other point not likely to be disturbed. The elevation is noted to the nearest foot in large figures in a conspicuous place near the point.

Note is made of the elevation of all crossings of roads, railroads, streams, bridges and summits, in front of public buildings or railroad stations and at any other point where it may aid the topographer in his work. The positions of contour crossings are also marked on the ground in some easily recognizable way for the use of the topographer.

In running unchecked or single primary level lines, two rodmen are sometimes used, each sets his own turning points from 10 to 20 ft. from those of the other man, but so as to keep his fore- and backsights of equal length, and two sets of notes are taken and calculatetd.

The secondary traverses consist of, first, the traverse proper, by which the length and direction of the lines is determined; second, the location of the details along the line of the survey; and third, the long direction lines taken to prominent objects at a distance from the survey line. The object of this survey is to locate points and large details that will prepare the way for the topographer, who follows, so that he can sketch in the remaining details without having to run extended survey lines.

The traverse party makes sketches of the country adjacent to the survey line as the work progresses, noting the distance and position of houses, stream crossings, and wood outlines, with respect to the survey line. After completing the traverse work at any station the instrument man takes sights on the prominent objects between roads, that will be of use in adjusting the traverse and in sketching by the topographic party. These will include prominent hill tops, corners of woods, prominent trees, etc. When the next traverse station is reached, the sketches for the last course are transferred to the traverse sheet. The nature of the details and the character of the points taken by intersection are indicated by conventional signs, as shown on the traverse sheet, Fig. 174. Where the traverse party finds elevations or bench marks left by a leveling party, they are located.

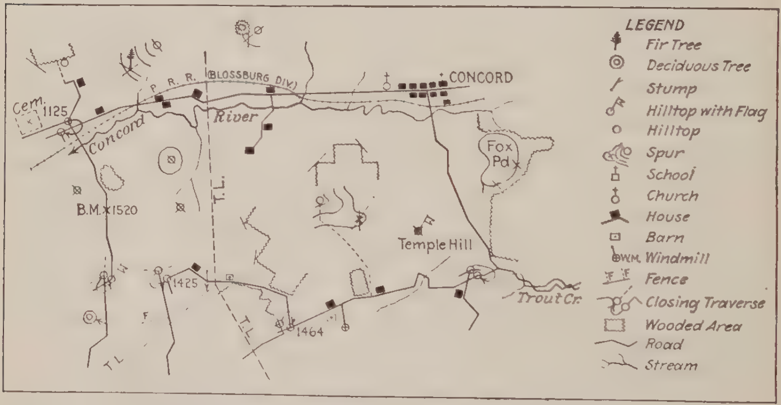

FIG. 174.—Secondary traverse for topography.

For the topographic work, at least two primary control points or lines should be plotted on each field sheet before commencing the field work. All existing maps of the section are sought for and the valuable parts of these are incorporated on the field sheets. The position and height of all bench marks are noted, so that the elevations obtained by aneroids will not be left without a check for distances exceeding 2 or 3 miles. The elevations obtained from railroad surveys are also added as being useful for checking.

The first work in the field is the running of the topographic control, which is done by the topographer as a plane-table triangulation. In these plane-table triangulations as many hill tops, buildings and notable features should be located as possible in order to afford numerous connections to the secondary traverse, previously run, and at the same time many additional points such as passes, gaps, important ridges, etc., should be located and their elevation determined so that they can be used as guides in sketching details. The plane-table triangulation is done on the large sheets at scales of 1:45,000 or of 1:90,000. All control lines are plotted and adjusted before the sketching of details begins.

The sketching of the topography may be done on separate traverse sheets but it must all be transferred to the main sheet in the field so that there will be no unfilled spaces, and the elevations must be shown by continuous contours. Where there are suitable facilities, the maps are sometimes inked in the field.

The maps are finished so that they are adapted to a photographic reduction of one-third, using colors that will photograph readily, namely, mixed burnt sienna for contours, Higgins's black for culture, and mixed prussian blue with about one-tenth burnt sienna or orange for drainage.

As the object of these topographic maps is to form a base for the geological data, the topographers locate all mines, quarries, open pits, prospects over 10 ft. deep, country coal banks, deep wells, etc., and obtain their elevations. These are plotted on the sheets in red but are not reproduced on the final topographic maps. Important mines, however, that have been in operation for some time and have changed the topography by their dumps or open pits, to an extent that will show on the sheet at the scale used, are properly included with the topography.

The geological notes are taken by a special party after the topographic work is completed, but geological features of great prominence should be located by the topographic party as identification or tie points for the later field work.[1]

Private Geological Surveys.—The refined methods of survey used by the U. S. Geological Survey are necessary for the Government work in the extensive areas covered in order to prevent an accumulation of errors, and so that when once made the basal surveys will not have to be repeated. For areas that will be treated in private work, the method can be modified so as to eliminate the geodetic surveys and employ the ordinary surveyor's instrument.

The *topographic survey* varies with the extent of the area to be investigated.

For work covering many square miles, a triangulation survey should be run for controlling purposes and this net should be subdivided by transit or plane-table surveys, and the details be filled in, similar to the secondary traverse just described. For tracts of only a few square miles in area, the triangulation would be omitted and the traverse would become the base survey, in which case the traverse should consist of closed circuits so as to afford checks within itself.

Where the secondary traverse[2] is controlled by a primary survey, it may be run rapidly, using the stadia to measure the distances. The plane-table is preferable for these surveys, as the map is built up and drawn in the field and so corresponds more closely with the ground.

The scale of the topographic map is influenced by the purpose for which it is to be used, and the size of the area to be surveyed. The contour interval is governed by the character of the country, and should be such that the map will not appear crowded; a distance between them of $\frac{1}{4}$ to $\frac{1}{2}$ in. on the map is desirable. A few advantageous combinations are as follows:

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[1] The work of the geological party is discussed on pages 310 to 313.

[2] From here to page 313 is an abstract, in the author's phraseology, of Chapters 2 to 5 of "Practical Field Geology," by J. H. Farrell, published by McGraw-Hill Book Co., New York, 1912. Reference should be made to this book for additional details of the method of collecting the geological data and especially for the application of that data.

Approximate area	Character of country	Scale	Contour interval
Extensive area	Bold features	1 in. = 500 ft.	30 to 100 ft.
4 sq. mi.	Moderately rough	1 in. = 300 ft.	25 ft.
4 sq. mi.	Low hills and gentle slopes	1 in. = 300 ft.	15 ft.
2 sq. mi.	Any kind of country	1 in. ≐ 150 ft.	10 to 15 ft.
Small area	Any kind of country	1 in. = 20 ft.	10 to 15 ft.

The scale must bear such relation to the size of the triangulation net on extensive surveys that at least three triangulation stations that can be seen throughout the area will appear on each working sheet.

In preparing for the field work, each plane-table sheet should have the controlling stations with their elevations plotted on it at the desired scale.

In the field the plane-table may be set at one of the stations plotted on the sheet, leveled and oriented; or it may be set up at any desired point and its position determined by the three point method. The rodman holds the rod on 15 or 20 points, along prominent ridges or drainage lines, on saddles, hill tops, etc., that have been indicated to him by the topographer, and which locate the characteristic features of the region. For accurate work, they should be within a radius of 1000 ft. The topographer reads the distance on the rod to his recorder, sets the horizontal wire on the top or bottom of the rod, motions to the rodman to move to the next point and then reads the vertical angle.

The recorder figures the horizontal distance to the point and its elevation from the data given him by the topographer and reads them back to the latter. The topographer plots the point and notes the elevation near it in small figures. When enough points have been located to control the area, and give the topographer an idea of the relation of the various features, he interpolates between elevations on uniform slopes for the positions of the desired contours, and with attention to the country before him, draws the contours as nearly like the ground surface as possible.

The beginner should take points at close intervals but as experience is acquired in reproducing the ground on paper, fewer controlling points will give the data. Accuracy is important on maps that are to be used for the location of geological data, and must not be sacrificed for speed.

The geological map should show, first, the areal geology, *i.e.*, the boundaries of the various kinds of rocks, with the dip and strike of sedimentary rocks; second, the structure, *i.e.*, the lines of faults with their dips and strikes and the angles and directions of their striæ, and the zones of crushing and brecciation; third, the outcrops of ore bodies, and of ore-bearing formations, with their dips.

In addition to the purely geological data, the property lines and the location of the principal underground workings should be obtained if they have not been noted by the topographer.

The observations of facts should be noted with great fullness and should not be confused with conclusions, opinions or theories. The latter may be recorded in the notes but should be kept separate from the facts. "So far as practicable, notes should be written while the objects described are being examined. In this way description is made more accurate and observation more thorough."

The geological data are conveniently plotted on the topographic map as a base, then the geologist can locate the geological features and plot them by their relation to the topography without having to make surveys. The best working sheets are white prints of the topographic map with either blue or brown lines, made from Vandyke negatives.

The scale used for the map may be controlled by the topographic map that is available. If the geological boundaries are well marked and not complicated and the formations few in number, a small scale of 1 in. = 500 ft. or even 1000 ft. may be used, especially if the area is large. On the other hand a large scale, as 1 in. =100 ft., would be desirable on a small area with complicated geological features, especially when the mine workings have been plotted to this scale. For most work of a moderate size, an intermediate scale of 1 in. = 250 ft. will give satisfaction.

The field equipment for collecting geological data will vary with the accuracy required. The surveying instrument for locating details, for rough work, or a reconnaissance, may be simply a pocket sight compass, dependence being placed on pacing for measuring the distances, but for careful work, a small plane-table with an open sight alidade is convenient as the geology can be added to the map in the field on the principle used to fill in the topographic map. A geologist compass of some type is always needed; this has a straight-edge parallel to the north and south line for taking the strike of a stratum and a clinometer for measuring the dip when the straight-edge is rested on the rock surface, in a direction perpendicular to the strike; it may have sights and be used in place of the pocket compass or it may be used for the preliminary orientation of the plane-table. A lens, a magnet, labels, a notebook, a geological hammer and a sack are essential for studying and collecting specimens. Colored pencils are often used to tint the areas on the map which are covered by the different rocks.

The field work should begin with a general reconnaissance of the area so as to give the geologist a general idea of the formation and the problems to be solved. If unfamiliar rocks or minerals are encountered, it is well to collect specimens and to determine them at this stage of the work, so that their full import may be known. The lines of travel, location of water and suitable camp sites should be noted on this trip.

The second step is to record the general geology of the area. The boundary of a formation or the line of division between two formations exists either as the rocks were originally formed or is the result of faulting or metamorphism at some subsequent period. These lines of contact of one rock with another are followed in the field and can often be plotted by the contours if the latter are well drawn. The plane-table can be set up at intervals and an exact location be determined as a check on the sketching. The dip should be obtained if possible.

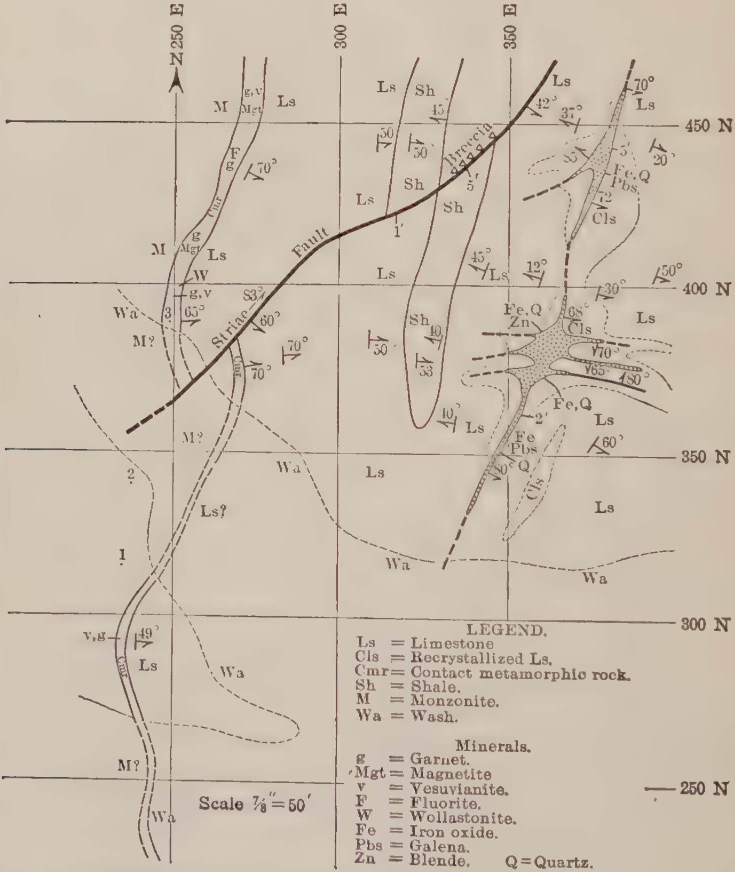

FIG. 175.—Working sheet showing the geological data recorded on the map.

Work within areas of the same formation is done by meandering, which is simply the process of covering the area by trips along the lines that offer the best chance for additional information. These are generally made across the strike of the formation so as to note the various characteristics of the rocks and any chance features as dikes, veins, etc.

The boundaries of rock areas are shown on the map as fine solid lines when certain, and as dotted lines when there is some doubt. The strike is indicated by a short line plotted in the proper direction; its course may be noted beside it. The dip is noted by a line normal to the strike, the direction is shown by the arrow point, and the amount by the angle noted.

Formations should be named according to the system used by the United States Geological Survey for the sake of uniformity; these can be obtained by reference to its reports.

The third step in the field work is to determine the details that have an economic value. This requires the mapping of faults, the outcrops of ore bodies, and the underground workings.

The course and dip of faults must be accurately determined. The possible occurrence of a fault is indicated by the contact of dissimilar rocks, by straight line features in the topography as cliffs and sometimes by water courses along lines of easy erosion. Slickensides are polished by the movements of the rocks and their surfaces sometimes show striæ which indicate the direction of the movement. The direction of the striæ should be noted. When a fissure contains mineral, it is called a vein and may have an economic value.

The structural features, such as folding, fracturing and shearing, and the alteration of country rock should be carefully observed in the neighborhood of the ore bodies, as any connection between the two may be of importance. Fig. 175 shows part of a working sheet, used in collecting surface geology. If necessary, additional notes can be recorded in a note book and cross references be made to the map by the latitude and departure of the points.

UNDERGROUND GEOLOGY

The study of underground geology has two divisions, first, the study of the rocks exposed in a mine in order to determine their stratification and structural features, and second, the study of the ore to determine the form of the deposit and the value of the ore for the purposes of inventory or purchase, or as a guide in working.

Geology of the Formation.—Systematic records of the nature of the rock and of the nature and value of the ore, should be made on every mine survey as the mine is worked. This data is easily collected as the mining progresses and the walls are freshly broken and clean, and being added to the map little by little, forms a mass of valuable information as time advances. Later the workings become blocked up and the information cannot be obtained, and even where they are open it is usually difficult to collect the data, as the smoke and dirt hide the nature of the rock and as it is usually impractical to examine large high workings in detail.

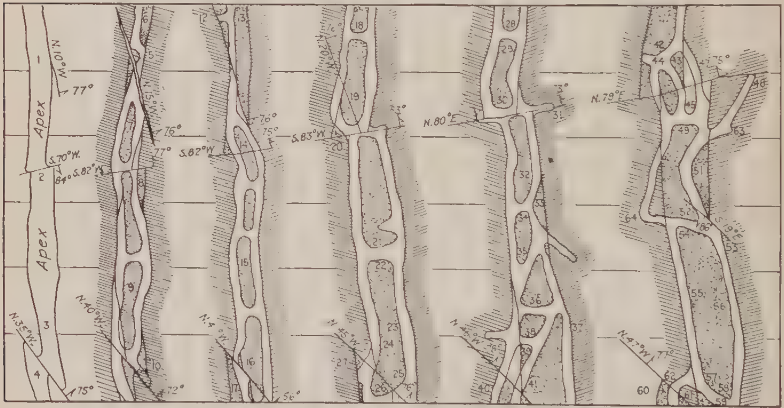

Fig. 176.—Geological map of a mine.

If the geological features have also been noted and plotted on the maps, many features of the stratification and structure of the region, that have been indicated by the surface exposures will be explained and be valuable guides in working the mine.

A geological map of a mine[1] is shown in Fig. 176, level by level; the horizontal lines show the traces of the same vertical planes on each level; the ore is indicated by the speckled area and the rock walls by the hatched areas; the figures on the ore are the numbers of the samples taken at those points, and the value of each sample, the thickness of the ore, etc., are recorded in a book under the corresponding number. The three faults that show on the surface reappear on the levels and account for the variations in the width of the vein.

The notes of the underground geology are most satisfactorily recorded in plots of the separate levels of the mine, drawn to the scale of the working map, 1 in. = 50 or 100 ft. The field notes are conveniently taken on sheets of cross-section paper, 8 by10 in., ruled to tenths of an inch. The sketch should show enough of the mine workings to make the conditions clear, or the field sheets may have the workings plotted on them from the mine maps before the geological work is begun. Notes are made on the sheets to explain the details and additional notes, if needed, are made in a small note book. Later the geology is transferred to the geological plots of the individual levels.

Geology of the Ore.—The character of the ore should be noted from time to time, especially if there is any change in its mineral contents. The thickness should be recorded at intervals. The recording of these peculiarities may show that the position of the rich ore follows certain laws that can be taken advantage of in the mining.

The collection of samples for assay purposes is called "sampling of the mine" and must be done carefully in order to be of any value. The best practice is to cut uniform grooves a few inches wide and an inch deep at regular distances apart, running across the entire face of the ore, and including all barren streaks that are mined, so as to get an average sample. This is difficult to accomplish as the tendency is to take a larger proportion of the softer material. The grooves are best cut with moils and a

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[1] From "Geological Mine-maps and Sections," by D. W. Brunton, *Trans. A. I. M. E.*, Vol. XXXVI, p. 508, 1905.

4-pound hammer. In veins of moderate width a sample taken every 10 ft. gives good results, but with narrow veins, the distance is often reduced to 5 ft. The position of the cuts is marked with chalk on the wall. It has been suggested that samples be taken every 20 ft. along the vein as a preliminary test, where an entire mine has to be appraised with a view to purchasing it, as this may show that the mine is of low value and not worth detailed sampling. The chips from the sampling grooves are caught on sheets or in pans or boxes and placed in sacks, one for each groove, and later the chips are ground, sampled and assayed. In active mines, the results of these samplings are noted on plots which have been copied from the mine maps.

In making an examination of a mine, there may be no available map and it may be necessary to make one, in order to describe the conditions and on which to show the location of the samples taken, the results of the assays and the positions of the rock features. For these purposes a map, made by some of the rough survey methods described in Chapter IX may suffice. The making of the survey and map prevents an oversight of any part and fixes the form of the workings in the mind of the examiner. Peculiarities in the form of the workings generally result from the nature of the deposit, and hence the geology of the ore body is indicated by the form of the mine, and the cause for the apparent eccentricities in the form of the workings should be investigated.

With ores, where the value may change without changing its appearance, like gold ore, it is customary to take frequent samples, to have them assayed and to record the results on an "Assay Map," so as to detect the presence of lean or barren areas and to work the mine accordingly. This sampling also shows whether the ore is increasing or decreasing in value in any part of the mine and so explains the reason for a variation in the returns from the mill, if such occurs. An assay map is thus a graphic record, drawn to scale, of the amount and value of ore in a mine.

One method of making the assay map is given in Fig. 177.[1]

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[1] Abstract from "Assay Maps," by Algernon Del Mar, *Min. and Sci. Press*, Sept. 8, 1904.

The shafts and drifts are shown by single straight lines, the width of the vein at every sampling point is plotted on the upper side of the drifts and on the right side of the shafts and winzes, and the value of the ore at these same points is plotted on the opposite side of the working. The points on both sides are connected and give the waved lines. The line representing width, may be drawn in a different color of ink from that showing the values, or one may be dotted and the other full.

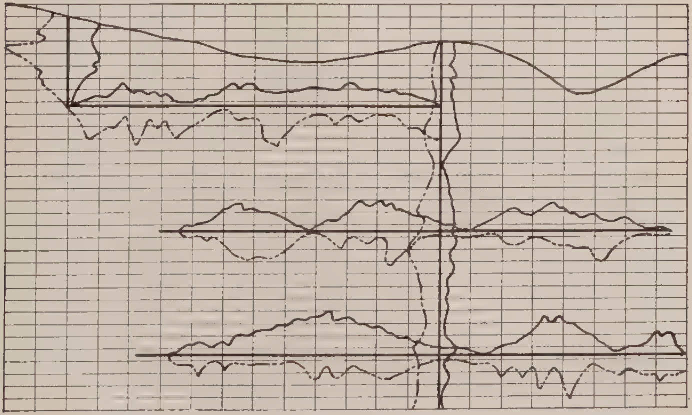

Fig. 177.—An assay map.

In the above figure, there are enlargements of the vein and increases of the values at three points on each level, which indicate that there are three pay shoots running diagonally down through the vein.

At the Meyer & Charlton Mine, in the Transvaal,[1] the notes taken in the sampling were: the mark on the sample; the distance from a reference point; the width of the ore, the waste, and the rocks that were sampled; and the stoping width of the vein. These were recorded in a book together with a sketch showing the vein with its stringers of ore and waste. After the samples had been assayed, the value of each sample was entered opposite its

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[1] Abstract of "Mine Sampling" by G. A. Denny, *Eng. and Min. Jour.*, June 27. 1903.

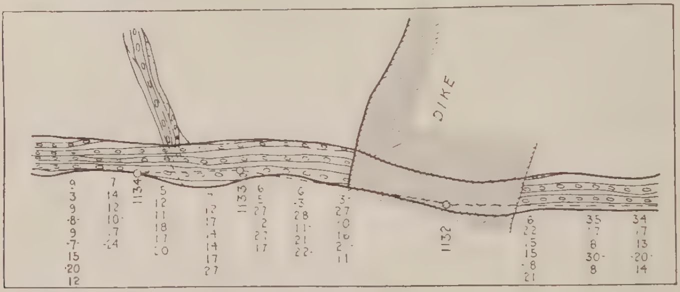
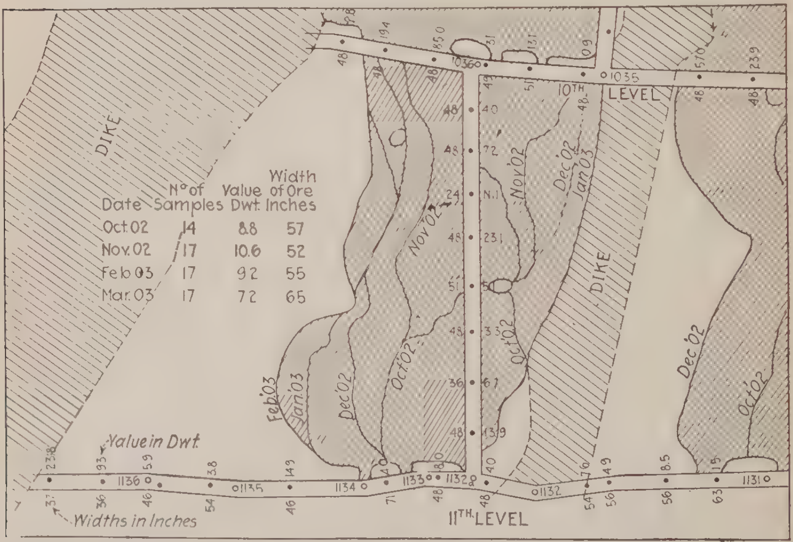


FIG. 178.—Assay map of a level. Meyer and Charlton Gold Mining Co., Transvaal, So. Af.



Date	N° of Samples	Value Dwt.	Width of Ore Inches
Oct. 02	14	8.8	57
Nov. 02	17	10.6	52
Feb. 03	17	9.2	55
Mar. 03	17	7.2	65

FIG. 179.—Working map of a mine, with stoping width and average values. Meyer & Charlton Gold Mining Co., Transvaal, So. Af.

record; where the samples were taken of every stringer and assayed separately, the average assay value of the vein for its stoping width was noted, and the assay-inches, *i. e.*, the product of the assay value of each stringer and the width of the ore represented by the sample, was given for each sample. The sketch was a continuous longitudinal section of the vein along the working being sampled and if any stringer of ore was missed in the mining, this sketch would detect it and it could be recovered. The mine was sampled at intervals of 5 ft.

The assay values were posted in two ways: First, along the levels, a plot of the vein was made as a continuous longitudinal section on which the width of each stringer was note opposite the sampling point, and the average value of the vein was indicated by the color of the tinting along the side of the section, see Fig. 178. Second, the ordinary development plan of the mine, had the stoping width and the average assay value of the vein, noted at every sampling point along the levels and the winzes, and the average value and the thickness of the vein was noted for the stope faces, see Fig. 179.

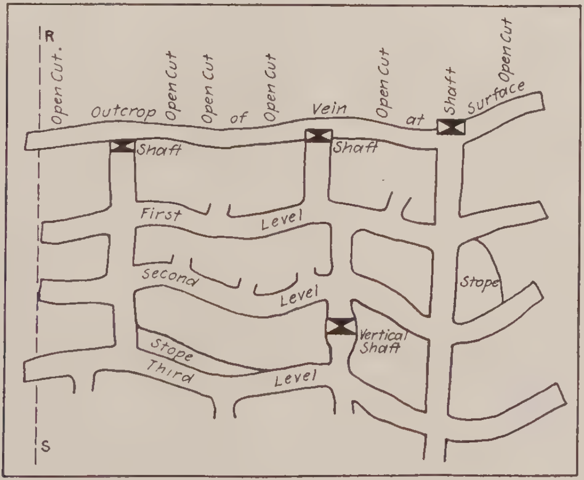


FIG. 180.—Plan of a mine.

The plan of another mine on a vein dipping about 60° is shown in Fig. 180. A line *R-S*, in any convenient position parallel to the dip, is taken as a base line and a diagram of the mine on the plane of the vein is drawn as shown in Fig. 181.[1] The levels are drawn perpendicular to the base line and at a distance

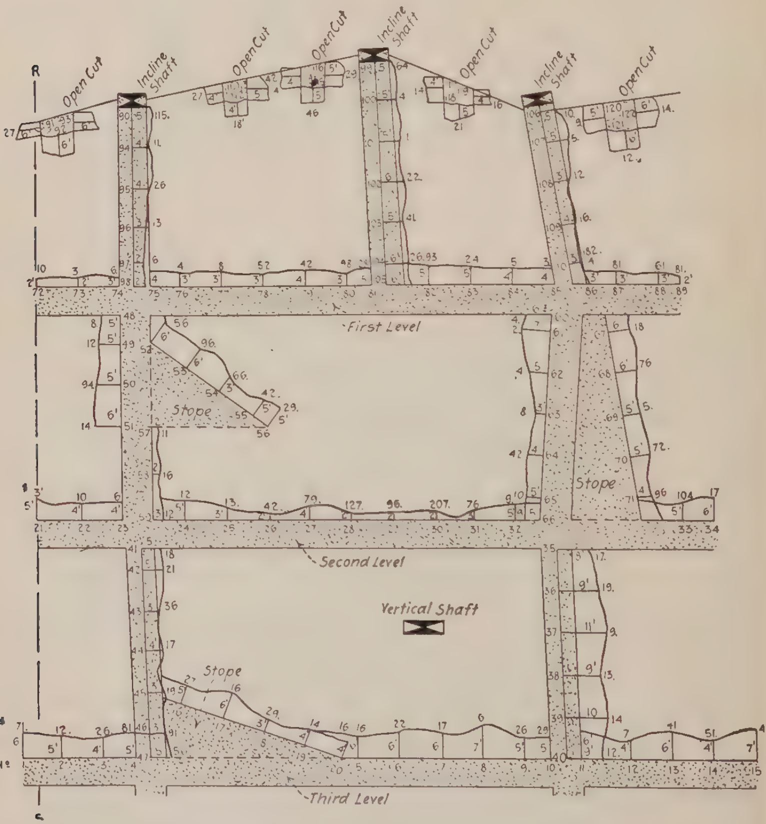


FIG. 181.—Assay map of the mine shown in Fig. 180.

apart equal to the slope distance between levels, and the warped surface of the vein is developed into the plane of the paper by plotting the winzes and shafts at their distances apart as measured along the levels. They are drawn as straight lines from level to level and may appear zig-zag in the diagram while in reality they are straight. The stope faces are also conventionalized. The position of the sampling point is indicated by a line normal to the line of the drift, the sample number is noted in the drift, the width of the sample is noted along the line, and the assay value to the nearest dollar is noted at its end. The length of the line is plotted to correspond with the width of the vein

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[1] Abstract of "Graphic Method of Mapping Exposed Ore Bodies," by G. W. Miller, Butte, Mont., *Min. and Sci. Press*, March 28, 1903.

Measurement of Ore Deposits.—In the case of coal seams or similar deposits, the volume of mineral within the limits of the property may be calculated with great accuracy. A survey can be made locating the outcrop of a coal seam and the area within this line can be easily measured from the map. The surface and underground explorations will determine the average thickness and what part of the area can be worked with profit. From this data, the volume of available coal can be calculated. The specific gravity of anthracite averages 1.5 and of bituminous averages 1.3, in the solid. The long tons of coal in an acre are approximately 100 times the specific gravity for each inch of thickness of the seam; thus for coal of a specific gravity of 1.3, there will be about 130 long tons per inch-acre. As there is a waste in mining and some coal is left in the pillars, it is safe to assume 100 long tons of coal per acre for each inch of thickness, as the probable yield. The volume of a seam will be the horizontal projection of the area on the property multiplied by the vertical thickness, irrespective of whether it is inclined or not.

Metalliferous deposits are more irregular than coal seams. In some cases, the average thickness of the deposit may be used in finding the volume but care must be taken in determining the thickness that the measurements are taken at equal distances and that greater weight is given to those near the center than to those at the edge of the deposit. In other cases, with irregular deposits, the volumes can only be obtained by making sections through them and calculating the volume from these by the prismoidal formula.[1]

Estimates of the quantity and value of ore in a mine should be based on facts, and a report should show, by plan and vertical section, the data from which the estimate is made. The plot should show the shape of the ore as found, or the formation as seen, and should clearly distinguish those facts from the conclusions that have been deduced. The width of the vein or pay shoot should be noted at regular intervals and samples should be taken at these points. The length, area, volume or weight which each sample represents should be noted in every case, and the locality from which the sample was taken should be shown on the plot. The samples must be taken so as to cross the banding. If the quality is regular, but the outline is variable, the measurements will have to be taken oftener than the samples. On the other hand, with a variable quality the samples should be taken close together.

This method of reporting will show what was observed and what was deduced, and it will also give data for checking up the conclusions without revisiting the ground. The report should show which person was responsible for each kind of data, who made the geological observations, who took samples, who made assays and who supplied plans.

BORE HOLE SURVEYS

Methods of Boring.—Exploring by bore-holes is often done where there is good reason for expecting the presence of an underground ore body. The hole may be bored either by cable-tools method used for artesian or oil wells, or by annular diamond or chilled shot drills.

With the *cable-tools*, the strata passed through are determined by collecting the sludge, settling it and examining the resulting sand. The thicknesses of the different strata are found by noting the depth at which the tool changes from one kind of rock to another, the points being determined by a change in the rate of the cutting of the tool and the character of the sludge that is brought up by the sludge pump. The holes are always started vertically and it is assumed that they continue both vertical and straight, which they are likely to do unless deflected by inclined strata of rocks of varying hardness. A "log" is kept of each hole in which a record is made of the depth of every change in the formation. If a number of holes are bored and their records are plotted to scale with reference to a known datum and the position of the holes are located on a map, information is obtained for determining the dip and strike of the rocks and other features of the underground geology. This method of exploring has the disadvantage that the mineral is pulverized and it is difficult to distinguish a valuable deposit from a low-grade one of the same mineral.

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[1] Abstract of "Examination of Mines," by H. S. Munroe, *S. of M. Quart.*, Vol. XII, p. 117.

Holes made with the *annular tools* bring an actual sample of the rock to the surface in the form of a core. The cores from diamond drills are from $\frac{3}{4}$ to 2 in. in diameter while from shot drills they are usually larger. The smaller cores are sufficient with hard firm rocks that do not break up and the larger cores are drilled in soft strata where the larger cross-sections are required in order to secure sound samples. Diamond drill holes may be bored at any angle and in rock of any degree of hardness. Holes made with core drills using chilled steel shot for cutters, are nearly always drilled vertically downward and are never inclined more than 45° from the vertical.

Direction of Holes.—The direction in which a hole is started can be determined by inserting a rod into the hole and measuring its dip and the direction of the vertical plane through it. The rod should fit the hole, in order to conform to its direction. The direction and location of the hole can both be found at the same time by setting the transit at a survey point near the hole and taking one sight at the rod at the mouth of the hole and another at a point higher up and measuring the horizontal and vertical angles and the distances to both points. The coordinates found for the lower point by these observations give the location of the hole. These coordinates combined with the coordinates of the upper point give the course and inclination of the hole. The distance between the two points on the rod can be calculated and should agree with the distance measured between them, thus forming a check on the observations and on the calculations.

Vertical holes tend to deflect when passing through inclined strata of varying degrees of hardness, owing to one edge of the bit working in harder rock than the other. The bit tends to follow the softer rock. This deflection is often neglected, it being assumed that the hole is really vertical, but there is no guarantee that such is the case, and when a deflection once starts, it increases as the hole deepens.

Inclined holes are deflected sidewise and vertically by the changes in the strata, the same as vertical holes, and further, have a tendency to become flatter due to the mechanical construction of the tools. The rods and core barrel, have to be smaller than the bit in order to turn in the hole, and the small diameter of the rods combined with their weight, causes them to lie on the lower side of the hole, and so tip the bit upward, and gradually change the direction of the hole.

At the *Chapin Mine*,[1] Iron Mountain, Mich., a diamond drill hole was started at 45° and pointing south. It struck ore at 725 ft. corresponding to the 8th level of the mine, if it had continued in the direction in which it was started. Later it was found by the mine workings on the 7th level, 96 ft. higher and 70 ft. south of its supposed position, due to the flattening of the hole.

The uncertainty of the direction of a deep bore-hole and the desire to determine the dip and strike of the strata, from a single hole have led to the practice of surveying of bore-holes. The dip of the hole is usually measured by some device for establishing a horizontal plane in a tube lowered into the bore-hole. Then the angle between this horizontal surface and the axis of the tube gives the dip. The direction of the dip is usually measured by using a magnetic needle.

[1] J. P. Channing, *Eng. Mag.*, Mar., 1896.

Hydrofluoric Acid Apparatus.—For measuring the dip, glass tubes partly filled with hydrofluoric acid, HFl, were proposed by G. Nolten, Dortmund, Germany, in 1880.[1] These are fitted into a shell and lowered into the hole by a light wire cord to the desired depth, and are left for about one-half hour until the acid has etched the glass. On withdrawing the tubes, each one is inclined so that the liquid coincides with the etched line, and the inclination of the tube is measured; the mean of these measurements gives the dip of the hole at the point where they stood.

In the Wassau District of the Gold Coast, West Africa,[2], the hydrofluoric acid used for etching had a strength of 33 per cent. and was contained in tubes of lead glass, fitted with rubber stoppers. Two of these tubes were placed in a brass cylinder, 7 ft. long; the cylinder was tightly closed, attached to a wire $\frac{1}{16}$ in. in diameter and lowered into the hole. The wire was conveniently wound on a drum 5 ft. in circumference, then the depth to which the apparatus was lowered was given by the number of revolutions made by the drum. The tube was lowered 100 ft. then allowed to stand for 5 to 7 minutes for the acid to etch the glass, then it was raised, the tubes taken out and emptied, and new ones with fresh acid put in and the apparatus lowered 200 ft., and another record taken; this was repeated for each 100-foot interval for the entire depth. The glass tubes were used over again by filling them up to the old etching with paraffine; this also economized in the acid. Mr. Justice found that it facilitated the setting of the tubes in the determination of the dip, to place a little mercury in the tube and push it up with a plunger until its surface agreed with the etched line, as the surface of the mercury reflected light which served to illuminate both the etching and the cross-wire of the microscope used to locate the etched line.

At the Michigan Copper Mining Co., Rockland, Mich.,[3] a common bottle, containing 35 per cent. hydrofluoric acid was placed in a blank bit, see *A* in Fig. 182, which was screwed onto the end of the core barrel, was lowered into the hole by means of the rods, and was allowed to stand for 30 minutes when it was withdrawn, and the angle of the etched line was measured with a goniometer. The holder for the glass bottle was made water tight by means of lead gaskets. The holes in the upper part of the holder were to permit any water that might be in the bore-hole to pass the apparatus in lowering it. When it was necessary to pump water through the tubes in order to cleanse the hole in lowering, the bottle holder was made small enough to go inside the core barrel, see *B* in the figure, and was held in place by a blank bit.

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[1] J. P. Channing, *Eng. News*, Mar., 1896.

[2] "Diamond Drilling in West Africa" by J. N. Justice, *Proc. Inst. of Min. and Met.*, London, Vol. XII, p. 301, and abstracted *Mines and Min.*, Nov. 1903.

[3] "Notes on Diamond Drilling," by Clarence M. Haight, *S. of M. Quart.*, July, 1909.

The deflection that may occur in a diamond drill is shown by the following record of a hole, 1191 ft. deep:

Depth below collar	Dip of hole
00 ft.	50°
175	58°
300	61°
535	61°
660	61°
800	64°
1080	64°

The direction of the dip, when hydrofluoric acid is used to give the inclination, is obtained by a magnetic needle that is locked by clock-work, after it has been in the hole for some time and had a chance to settle.

Gelatine Apparatus.—An instrument of this type, invented by E. F. Macgeorge of Victoria, Australia, about 1883,[1] consists of several clear glass vials nearly filled with a hot solution of gelatine, each containing a free magnetic needle in suspension, and all held in a brass protecting tube. The tube is let down the hole for the required depth and allowed to remain for several hours until the gelatine has set. On being withdrawn, the vials are replaced at the angle at which they had cooled by bringing the congealed surface of the gelatine to the horizontal, then on revolving the tube until the needle is again in the magnetic meridian, the tube is in the same position both as to azimuth and inclination as it was in the bore-hole. The mean of the results obtained from the several tubes is used as the direction of the hole at the point of observation. A deviation of 37 ft. in a vertical hole 370 ft. deep at the Scotchman's United Mine, and one of 18 ft. in a vertical hole 300 ft. deep at Crown Cross United Mine, both at Stawell, Victoria, were found with this apparatus.

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[1] Abstract of "The Clinograph or Bore-hole Test," *Engineering* (London), Mar. 13 and April 3, 1885, Vol. XXXIX, pp. 260 and 334.

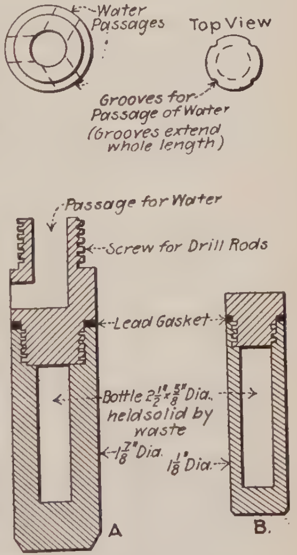
Water Passages
Top View
Grooves for Passage of Water (Grooves extend whole length)
Passage for Water
Screw for Drill Rods
Lead Gasket
Bottle $2\frac{1}{2}'' \times \frac{5}{8}''$ Dia. held solid by waste
$1\frac{7}{8}''$ Dia.
$1\frac{1}{8}''$ Dia.
A
B.

FIG. 182.—Holders for hydrofluoric acid bottles.

The indications of the dip by the congealed surfaces are not entirely satisfactory, due to capillary attraction, the unequal adhesion of the gelatine to the two sides of the tube and the unequal refraction of the glass. These difficulties are overcome by the improved tube shown in Fig. 183, called a "clinostat" by Macgeorge, in which tiny plummets as well as magnets are immersed in the gelatine.

The lower end of the vial is made spherical and this contains the magnetic needle to which is attached a glass float, so proportioned as to make the needle stand upright on its pivot in every position of the vial, but still allowing it to assume the meridian without touching the sides of the bulb. Passing through an air-tight cork and screw cap at the upper end is a smaller glass tube terminating in another bulb at the top and at its lower end, entering a cork in the neck of the main vial. The upper bulb contains a delicate plummet consisting of a glass rod terminating in a solid ball at the bottom and a hollow bulb at the top which cause it to float vertically for all positions of the vial. It, like the magnet, is carefully adjusted to the specific gravity of the liquid in which it is immersed and is provided with a minute bearing point at its upper end.

In preparing the clinostats for making a test, they are immersed in water at 180° F. until the gelatine is melted, and are then placed in a tight brass cylinder about 6 ft. long holding six clinostats. These cylinders are strong enough to resist the heaviest water pressure likely to be encountered, and are water tight to protect the glass vials from the pressure. The cylinder is then lowered by a ½-in. iron pipe jointed in measured lengths so that the depth at which the test is made can be easily ascertained. The section next to the clinostat cylinder is of brass so as not to affect the needle. In vertical holes, the cylinder can be lowered with a piece of wire cord instead of the pipe. They are left in the hole until the gelatine has had time to harden and lock the plummet and needle in their respective positions.

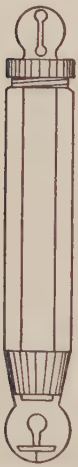

Fig. 183.—The Macgeorge clinostat.

When the clinostats have been withdrawn from a hole, they are placed in a special instrument in which they can be tilted until the plummet is vertical and the holder can be rotated until the needle is in the magnetic meridian, then the horizontal and vertical angles to the tube are read from the scales on the instrument and these give the course and dip of the bore-hole.[1]

The direction of the dip and strike of the strata at the bottom of the hole may be obtained by attaching a brass core extractor to the end of the tube holding the clinostats, forcing the extractor down by means of the rods over the end of the core projecting in the bottom of the hole so that the core is siezed and broken off; and leaving the apparatus until the gelatine has set, when the position of the core is recorded, and on replacing it at this angle after it has been withdrawn the direction of the dip and strike of the strata can be measured.

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[1] This instrument is illustrated in the article in *Engineering* referred to on p. 326.

Mr. Justice notes[1] that there is a good deal of trouble in manipulating the gelatine. The rubber corks are apt to push out of the tubes as the gelatine expands on being heated. Bore-holes sometimes contain water of 70° to 80° F. which delays the hardening of the gelatine and the increase in the time required for the heat of the melted gelatine to work out necessitates a long stay in the hole. The gelatine spoils if air gets into its containing tube. If the tubes are kept a long time before using, the needles lose part of their magnetism, and are not positive in their action; they also rust and stain the gelatine so that the north end of the needle cannot be recognized through it. He recommends the use of a mixture composed of "agar-agar," an extract of an Eastern seaweed, also called Bengal isinglass, in the proportion of 5 grams to 1000 grams of water to which 1 drop of formaline has been previously added as a preservative. This mixture melts at 194° F., boils at 221°, sets firmly at 104°, and is very stable. It is not as clear as gelatine and this makes it difficult to identify the north end of the needle but this can be somewhat improved by adding a little white of egg.

Marriott's Apparatus.—In an instrument devised by Hugh F. Marriott,[2] a needle with a small mirror attached to record the dip, is held by solid paraffine until the apparatus has been lowered to the desired depth, when an electric current is passed through a resistance coil in the wax, melts it, and frees the needle and the mirror, then on shutting off the current the needle settles, and the wax cools and reclamps the parts.

The needle, *L*, Fig. 184, is attached to a hollow conical base, and is hung at the top of a long pivot so that the center of gravity of the cone is below the point of support and the needle assumes a horizontal position even when the instrument is somewhat out of the vertical. *M* is a small silver mirror. After the needle is in place, melted paraffine is poured in around the coil and to a height sufficient to lock the cone when it is cold.

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[1] *Proc. Inst. of Min. and Met.*, London, Vol. XII, p. 301, and *Mines and Min.*, Nov., 1903.

[2] *Proc. Inst. of Min. and Met.*, Vol. XIV, p 255 and *Eng. News*, July 27, 1905.

An improved form is shown in the second view. The needle is mounted in a hemi-spherical dish, *O*, which is set in gimbals and hence will become horizontal in whatever position the instrument may be placed, when the paraffine surrounding it is melted by the current. A little melted paraffine is also poured into the dish, so as to seal the needle when it cools around the lower end of the cone. This separation of the needle from the mass of the paraffine prevents it from being disturbed by any action of the melting material. The outside paraffine fills the space around the coil and halfway up the side of the cup, thus both locking and heating the cup.

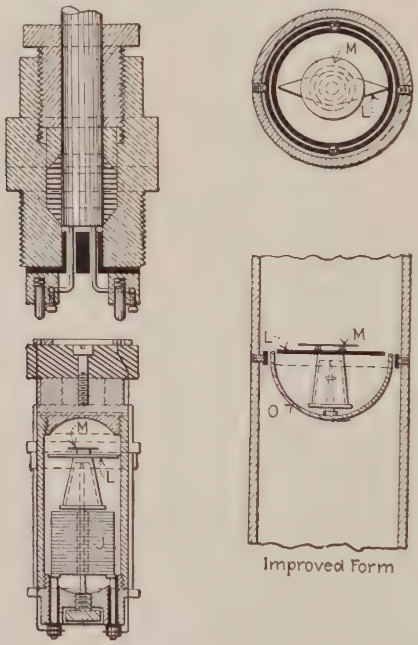

Fig. 184.—Marriott's apparatus.

For making a test the apparatus is assembled, the electric connections are made, the tube placed in a strong retaining cylinder, and lowered to the desired point in the hole. Then the current is passed through the resistance coil, J, and the wax is melted; after the current is shut off, the needle settles, the wax resets and the apparatus is withdrawn. The inclination of the hole is obtained by measuring the angle between the mirror and the cylinder and the direction of the hole is found from the position of the needle. These measurements are made by a simple protractor to which the instrument is clamped.

This arrangement of holding the recording device until the point to be measured is reached, prevents false records being made by the indicator taking its position during the lowering or raising of the instrument, but the principal advantage of melting the wax in the hole is that a quicker melting and cooling substance can be used.

The containing cylinder is lowered by a ½-in. wire rope, containing two insulated conductors in its interior. These lead to contact rings, on the sides of the drum on which the rope is coiled, and through which a pair of brushes make connection with the current supply. A measuring wheel over which the rope passes gives the distance down the hole to the apparatus.

A second appliance,[1] also devised by Hugh F. Marriott, gives a continuous record of the inclination of a hole, but does not give its direction. It consists of a strong case, see Fig. 185, containing a half cylinder B, pivoted on its long axis, and weighted at W, so that the closed side of the half cylinder will always turn downward when the case is tilted from the vertical or laid on its side.

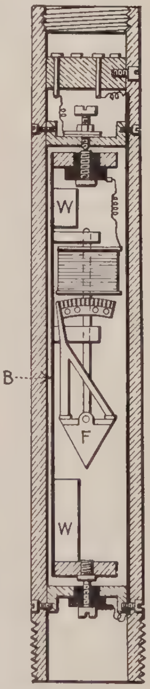

Fig. 185.—Marriott's continuous record apparatus.

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[1] *Proc. Inst. of Min. and Met.*, London, Vol. XIV, p. 255, and *Eng. News*, July 27, 1905.

This brings it into such a position that another weight *F* and its attachments move in a vertical plane by gravity as the inclination of the hole changes. This causes an arm to move across the contact points and throw different amounts of resistance into the circuit for different inclinations. This variation in the resistance is indicated at the surface and gives a continuous electrical record which, compared with previous calibrations of the instrument, shows the inclination of the bore-hole throughout its length. The case containing the instrument is lowered by a ½-in. wire rope which contains two conductors. The rope is wound on a drum, with contact rings as previously described for Marriott's other instrument, and connects the apparatus in the hole with the recording instrument on surface. The depth to which the instrument is lowered is indicated by the length of rope lowered.

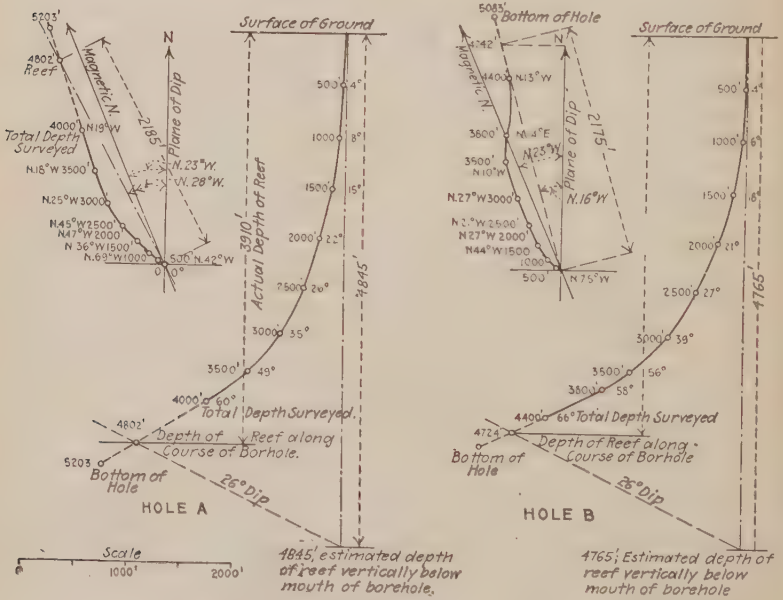

FIG. 186.—Results of bore-hole surveys.

The results of surveys of two holes at the Turf Mines, Ltd., near Johannesburg, made with Marriott's instruments, are shown in Fig. 186. Hole *A* was bored within 1100 ft. of the north boundary of the property, and gave the apparent depth to the reef, assuming that the hole was vertical, as 4802 ft. On surveying the hole, it was found that it deflected toward the N. W. at the start and then turned northerly, striking the reef 2185 ft. horizontally from the mouth of the hole, and at a vertical depth of only 3910 ft. The reef has a mean dip of south 26° and hence the actual depth of the reef below the mouth of the hole was estimated as 4845 ft. The rocks dip toward the south, hence the hole deflected until it was normal to the dip and then continued to flatten. Hole *B* deflected both horizontally and vertically in a similar

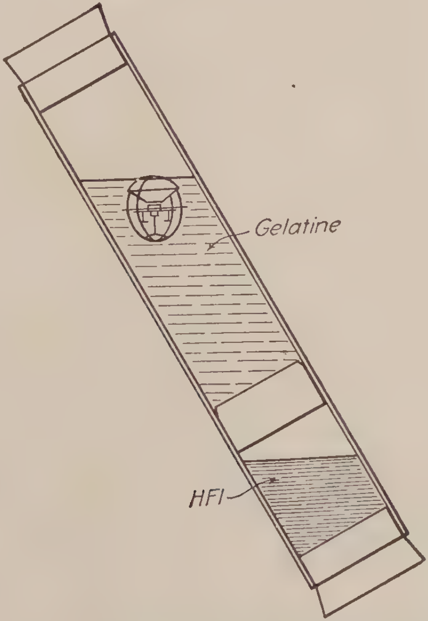

FIG. 187.—Combined gelatine and hydrofluoric acid apparatus.

manner to hole *A*. The courses of both holes are shown by a plan and a vertical projection on the plane of the dip. The holes could only be surveyed to a depth of 4000 or 4400 ft., respectively, possibly because they became so flat that the instruments could not slide down any further or because they became inoperative at the flatter inclination.

These cases illustrate the necessity of surveying a bore-hole when any calculation of the position of an ore deposit is based on it.

Combined Gelatine and Hydrofluoric Acid Apparatus.—The method in vogue at the mines of the Cleveland-Cliffs Iron Co., Michigan,[1] consists of determining the inclination of the hole by etching a glass tube with hydrofluoric acid, and recording its direction by locking a compass needle in cooling gelatine. The apparatus is shown in Fig. 187.

The compass is pivoted in a cage, which prevents it from coming in contact with the sides of the tube while still allowing it to swing freely, and the cage is attached to a cork which floats on the surface of the gelatine. The tubes are about 1 in. outside diameter by 6 in. long and open at both ends. A rubber stopper is pushed into the tube so as to give an acid chamber at one end about 1½ in. long. Other rubber stoppers close the ends of the tube. The acid used is 1 part hydrofluoric acid to 12 parts water. The gelatine is made by dissolving $\frac{5}{6}$ gram of "Nelson's Improved Brilliant Gelatine" in 50 c.c. of water, which gives a mixture that would keep liquid for the maximum length of time when lowered into the hole and still be solid when cold. The ground waters in Michigan where the instrument was used had a temperature of 43° F., and tests were made to determine the rate of cooling of the gelatine in water of this temperature. These experiments showed that for holes that require over 20 minutes for the lowering of the tools, it is necessary to retard the cooling of the gelatine by wrapping the tube with several layers of paper, and for very deep holes, to use a thermos bottle with a vacuum jacket, to hold the gelatine and keep it fluid for 50 minutes.

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[1] Abstract of "Surveying and Sampling Diamond Drill Holes," by E. E, White, *Trans. Lake Sup. Min. Inst.*, and *Min. and Eng. World*, Nov. 25. 1911.

In using this apparatus, the hot gelatine is poured into the tube, the latter is immersed in boiling water and heated as hot as possible, the compass is dropped in, and the end plugged, about 1 in. of acid is placed in the other end, that end closed, the tube is then wrapped in paper, and placed with the gelatine end up, in a brass containing tube, which in turn is attached to the end of a 20-foot brass rod on the end of the drill rods. The tubes are left in the hole for about 50 minutes after the rods are lowered to give the gelatine time to set and the acid time to etch the glass. On being withdrawn, the N. and S. points of the compass are located on the glass tube by sighting across the two pins projecting down from the needle and are marked on the glass with a diamond point; then the tube is washed out and the compass dried to prevent rusting. The tube thus forms a permanent record of the inclination and direction of the hole at the point where it was tested. The inclination of the etched line is read in a goniometer and corrected for capillary attraction, which has been determined experimentally for each size of tube. Tests have been made to a depth of 2000 ft. with this apparatus. A comparison of a series of observations at different points in a hole will generally show whether there is or is not any local attraction present.

Direction of Dip Determined Without a Needle.—In surveying in magnetic formations, the needle cannot be used to give the direction of the hole.[1] The rods must then be used to orient the gelatine tube at the bottom. They are screwed together in long lines on surface, in the order in which they will be lowered into the hole, each joint will be screwed up tight and marked exactly in line with the mark at the previous joint, so that all the marks will make one continuous straight line, throughout the entire length. The acid tube is similarly marked with a scratch in line with the marks on the rods. The rods are then taken apart and lowered into the hole, care being taken to screw the joints up so that the marks exactly match, and that the rods are not twisted in the hole, then the position of the mark on the acid vial is given by locating the mark on the last rod at the surface. Tests for the direction of a hole made by this method do not agree very well, the direction in non-magnetic holes sometimes differs 10° or 20° from the direction obtained by the compass method.

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[1] Abstract of "Surveying and Sampling Diamond Drill Holes," by E. E. White, *Trans. Lake Sup. Min. Inst.*, and *Min. and Eng. World*, Nov. 25, 1911.

CHAPTER XV

MAGNETIC SURVEYS

Magnetic surveys utilize the magnetic property of certain minerals to detect their presence in the ground. While many minerals are somewhat magnetic, the magnetic iron ore or magnetite, Fe_3O_4, is practically the only one that is sufficiently magnetic to enable its presence to be detected with a needle.

There are three general methods of making magnetic surveys in vogue, viz:

1. With dip compass,
2. With horizontal compass,
3. With magnetometer.

The first and second are largely qualitative, and the third is a combination of the first and second methods with modifications intended to give some quantitative information as to the ore body.

The laws affecting the needle under various conditions are discussed under the magnetometer but many of these apply equally to the dip and the horizontal compass.

DIP COMPASS

The dip compass consists of a magnetic needle hung on an horizontal axis so that it will swing vertically and balanced so that, being placed in the plane of the magnetic meridian, at the locality to be investigated, it will stand horizontally, or at zero, when there is no local attraction. Then on being brought into the presence of a magnetic substance, one end of the needle will be deflected downward and its angle of deflection called the dip, can be read. When the north end of the compass needle is drawn downward the needle is said to have a *positive* dip and when the south end of the needle is drawn downward it is called a *negative* dip. Two patterns of this compass are in use as shown in Fig. 188.

The needle may be balanced when it is made, but after it has been magnetized, the north end, in the northern hemisphere, is pulled downward by the magnetic attraction of the earth, and it must be rebalanced by adding fine brass wire to the south end. As the intensity of the earth's attraction varies at different places, the needle must be balanced near the locality to be investigated, but in a place where there is no local attraction. The freedom of a place from local attraction may be proved by observing the declination of an ordinary compass with respect to a true meridian and if it agrees with the declination of that region, it is reasonable to assume that there is nothing in the vicinity to affect the vertical angle of the dip needle. Further proof that the place is not disturbed by magnetic bodies is obtained by taking the dip at a number of points over a considerable area; if these

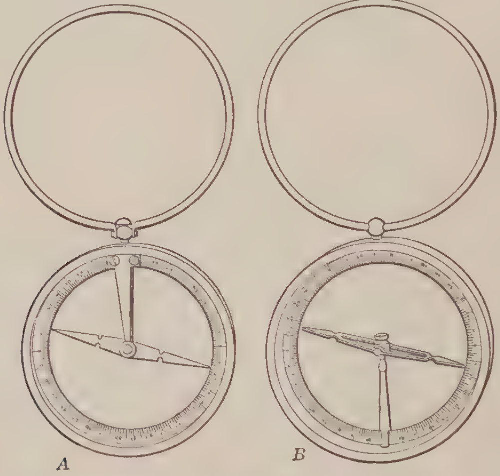

FIG. 188.—Dip compasses. Made by W. & L. E. Gurley, Troy, N. Y.

are fairly constant the mean may be taken as the normal attraction of the earth in that region.

In all observations with a dip needle, it must be set in the plane of the magnetic meridian, so that the attraction will not cause a side thrust on the pivot, and so that the maximum effect of the vertical attraction will be obtained. The style shown at *B*, in the figure, is intended to ensure that the needle is in the magnetic meridian by making it free to turn a little about the vertical pivot. The amount of dip that can be measured with this style is somewhat limited and style *A* is the one usually used, dependence being placed on a separate horizontal compass to give the direction of the meridian for setting the dip compass.

Bodies of iron ore lying in the earth acquire a slight polarity due to the flow of the magnetic currents of the earth through them, and by their mass exert an influence on a needle even when considerably removed from them. The nature of the magnetic field produced by an ore body is determined by measuring the dip at a number of points on the surface, plotting these on a map and then drawing lines through the points of equal dip, similar to the passing of contours through points of equal elevation. These lines are called *isoclinic* lines. If iron filings are sprinkled on a sheet of paper placed over a strong magnet, they arrange themselves along the lines of force radiating from the pole, and indicate the nature of the field. The isoclinic lines are normal to the lines of force and are adapted to indicating the nature of a mild but extensive magnetic field.

The magnetic intensity of an ore body, that is, the strength of its attraction, depends on, first, the position of the ore body with respect to the earth's currents, as this controls the amount of its polarity; second, the mass of the ore body, since its intensity is directly as its mass; and third, the distance of the ore body from the needle, since the intensity varies inversely as the square of the distance. From the last two it can be seen that a small body near the surface may exert as great an attaction as a large body at a distance, but its effect will extend over a smaller area. Hence the general conclusion can be drawn that a slow and steady increase of dip over a large area indicates a large deep-lying deposit, while a large dip limited to a small area and falling away rapidly is indicative of a small deposit.

A variation in the richness of the ore complicates any attempt to judge its depth, as lean ore near the surface might cause the same indications as rich ore at a depth, where both covered a large area.

Magnetic Surveys.—The magnetic survey of a tract is made by measuring the dip of the needle at the corners of squares. For most work, these are conveniently run 100 ft. on a side, then if necessary, intermediates can be run in important or complicated places. For a preliminary investigation of a region, it may be sufficient to note the dip at intervals of several hundred feet. In the office, the squares corresponding to those on the ground are laid out on the map and the dip is recorded at each corner, and the isoclinic lines are drawn. Areas of large dip are sometimes tinted heavily and other areas of low but positive dip are tinted lighter, and still other parts having a negative dip are tinted a different color.

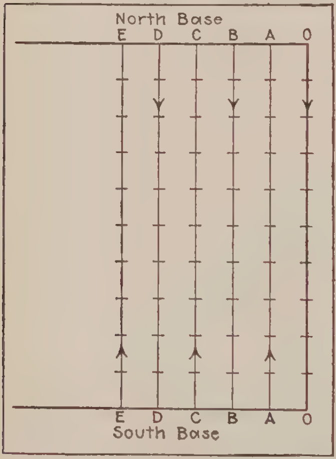

Fig. 189.—Diagram of a magnetic survey.

A convenient method of carrying on the survey is to lay out two parallel base lines at a known distance apart, preferably at some multiple of the side of the square that is to be used; their zero ends are connected by a line perpendicular to both of them; and stakes are set along the base lines at distances equal to the side of the squares, see Fig. 189. The two base lines should be in sight of each other, so that lines connecting corresponding points can be ranged in by eye. If the country permits they may be placed 1000 to 1500 ft. apart, but in rolling country they may have to be closer together or there may have to be several of them. The base lines should be connected with the traverse system of the property so that they can be plotted on the maps. If the line O to O runs north and south, the dip compass can be set in the approximate magnetic meridian by turning it through the angle of declination as judged by the eye.

The survey is started by placing a flag pole at O_S and at A_N, then the observer sets up and reads the dip at O_N on the north base, sends out the helper with the forward end of the tape or chain, equal in length to the interval, lines him in with the flag on O_S, when he plants a pin at the end of the tape, then both move forward, the observer sets up and takes the reading at point No. 1, sets the chainman in line for the next forward point as before, pulls up the pin, and both again move up. On reaching the south base, the observer returns the pins that he has collected to the chainman, after counting them, the flag is moved to point B_S of the south base so as to be in position to be used as a foresight when running south on the line B to B. Then starting at A_S, the line A to A is run north and observations made at the required intervals. Each time a line is finished its flag is moved two intervals so as to be in position for the next line run toward that base. If the distance between the two base lines is not too great, the cross lines might be paced instead of being taped; this would sacrifice a little of the accuracy, but would save the expense of a chainman.

Instead of plaiding off the country from two parallel bases, a line may be run through the center of the tract to be surveyed, and at intervals along this center line branch lines may be run at right angles and readings of dip taken at regular intervals on these lines.

A map of the magnetite deposits at Mineville, N. Y., is given in Fig. 190,[1] showing the results of the magnetic surveys made previous to 1893 by isoclinic lines and the mine workings to 1913 by shaded areas. The isoclinic lines may be identified by the dips noted near them. The surface contours are distinguished

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[1] By courtesy of Witherbee, Sherman & Co., Mineville, N. Y.

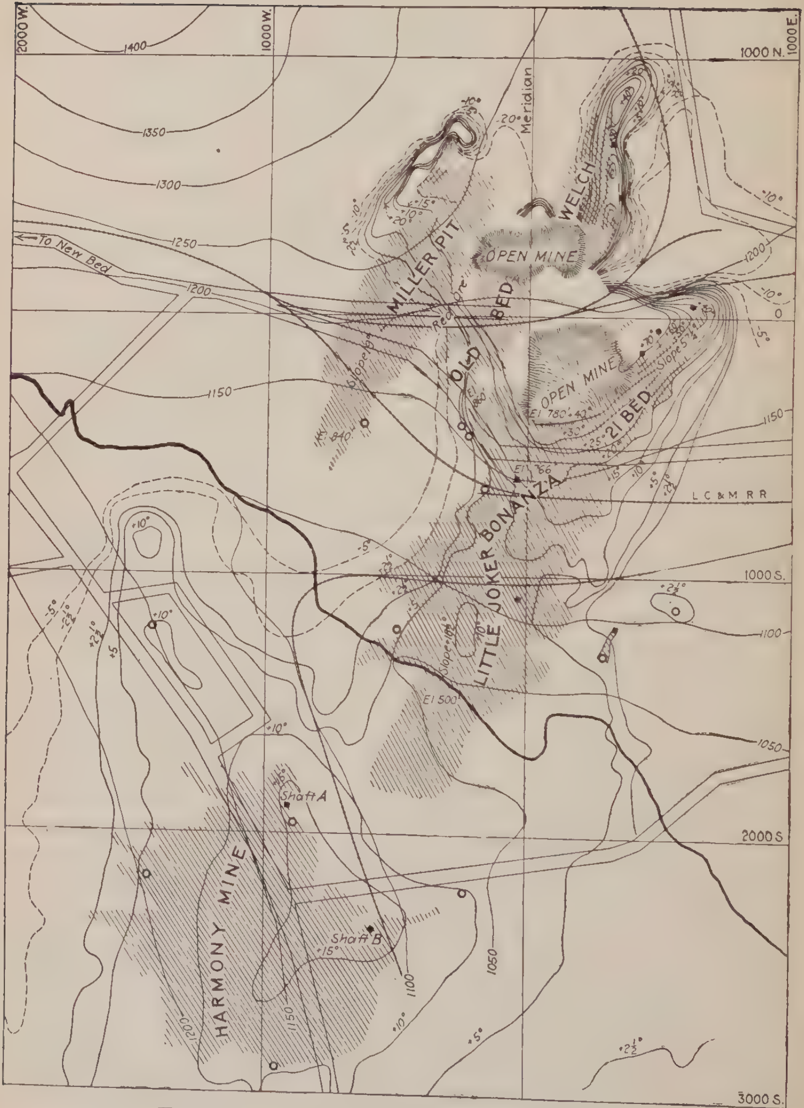

Fig. 190.—Magnetic Map, Mineville, N. Y.

by having their elevations noted in a gap in them. The elevations on the workings give the elevation of the foot wall of the deposit at those points. The shafts are shown by solid black squares and diamond drill holes are indicated by heavy circles.

At the time that the magnetic surveys were made, the ore was being mined from the "21 Bed" and the "Joker" and "Little Bonanza" mines which were apparently on a continuation of the "21 Bed." To the north and west of this group there were old workings which were idle but contained some ore in the pillars and in the wall rocks.

The lines of large dip encircle the outcrop of all the ore bodies in an irregular way; then the dip grows less toward the south as the ore becomes deeper, and the isoclinic lines begin to close in. Thus far the attraction is similar to that resulting from a single deposit, the 10°-line crosses from the east to the west side, but the 5°-lines flare outward and enclose a large area to the south before they finally close on themselves. The maximum dip in this area is only 15° but it occurs where the dip due to the main ore bodies would be small or even negative and hence must result from some powerful influence. This condition was noted at the time the magnetic surveys were made; the area was prospected by several diamond drill holes, later Harmony shafts "A" and "B" were sunk and an important mine developed as shown by the hatched area.

The map thus illustrates the large positive dip that occurs near the outcrop of a massive deposit like the "21 Bed"; the gradual decrease of the dip as the ore body becomes deeper and the point of observation is further away from the pole; the interference with the regular decrease of the dip by the Harmony ore bed, and the extensive and well defined area of rather low dip that results from the large deep-lying Harmony deposits.

HORIZONTAL COMPASS

A magnetic ore body causes local attraction which deflects the needle of the ordinary compass. By measuring these deflections and plotting them, lines of equal deflection or *isogonic* lines can be drawn by which the presence of an ore body is indicated.

In making a survey with a horizontal compass, the country is plaided off and observations are taken at the corners of squares in a similar manner to that used in taking dips.

If an ore body is present, it will cause a deflection of the needle from the magnetic meridian. These deflections can be noted on a plot and the isogonic lines can be drawn through the points of equal deflection, or small arrows pointing in the same direction as the compass needle can be plotted at each point.

The upper part of any deposit attracts the north end of the needle and may be called the pole area. The position of an ore body affects the intensity of its attraction, those lying north and south being much more magnetic than those that lie east and west.[1]

If the axis of a deposit is north and south, there will be an area on the east and the west sides of it where the deflection is maximum but in opposite directions, outside of these maximum areas the deflection gradually decreases to the normal on each side, and between the maximum areas the deflection gradually decreases until it becomes zero. A line passing through these points of no deflection is called the magnetic axis of the deposit and generally conforms to the long dimension of the deposit. The dip along this magnetic axis is greater than at points to the east or west of it.

If the axis of a deposit runs east and west, and the body is approached from the south, the needle may be little affected until the deposit is reached, when it will be deflected suddenly; at the north of the body, the needle may point southerly when near the body, decreasing as the distance increases until a point is passed where the needle is indifferent and may point in any direction as the attraction of the deposit equalizes that of the earth, then still further north it will gradually return to its true position.

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[1] These phenomena are discussed in detail by H. L. Smith in a paper on "Magnetic Observations in Geological Mapping," *Trans. A. I. M. E.*, Vol. XXVI, p. 640.

The south pointing of the needle and a point of indifference may also be found to the north of deposits which have a north and south direction.

For exploring a new locality, for possible deflections, and when it is not convenient to establish a system of base lines, a dial compass may be used to establish a meridian at any point from which the deflection can be read. This instrument consists of a compass with the addition of an hour circle and a gnomon, or style, set on the north and south line of the compass. Then when the instrument is level and is turned so that the shadow of the gnomon indicates the same time as given by a watch set for local apparent time, the north and south line of the compass is approximately on the meridian and the needle indicates the

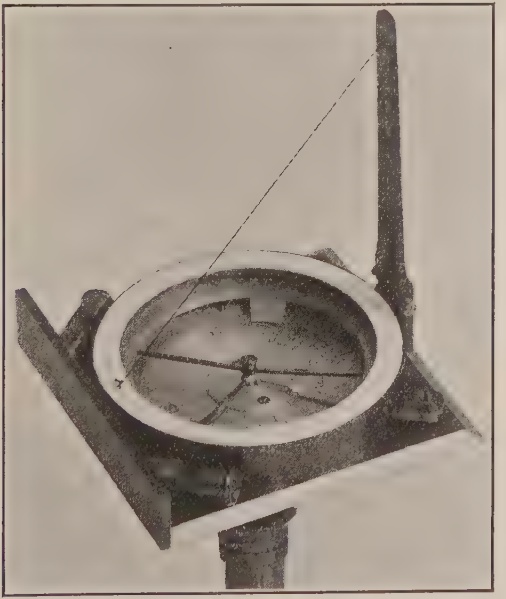

Fig. 191.—Dial compass. Made by W. & L. E. Gurley, Troy, N. Y.

declination. Fig. 191 shows a dial compass having a silk thread for the gnomon, and also provided with a pendulum clinometer for geological work. The angle of the gnomon must agree approximately with the latitude of the place and the hour circle must be graduated for that latitude.

Attempts have been made to determine the intensity of the horizontal component of the attraction of an ore body by pulling the ordinary compass needle to one side and noting the number of oscillations per minute made by the needle. In the vicinity of an ore body, the increased horizontal attraction causes the needle to oscillate more rapidly than in the normal field; the square of the number of oscillations being proportional to the strength of the field, gives a relative measure of the intensity. Knowing the direction of the normal magnetic meridian, and the direction of the needle near the ore, and the relative intensity of these forces, the force diagram can be drawn which will show the direction and intensity of the local attraction.

MAGNETOMETER

The magnetometer is a Swedish instrument for measuring the vertical and horizontal intensity of a magnetic field. If the field is disturbed by magnetic ore bodies, it enables some conclusions to be drawn as to the location of the ore.[1]

Properties of Magnets.—The force with which magnets attract or repel each other is proportional to the product of the strengths of their poles and inversely as the square of the distance between the acting poles. If P and p, are the strengths of one pole respectively of each of the two magnets, and d the distance between them, then the force acting between them is:

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[1] The first full account of the Swedish instrument and method of using, written in English, was given by Dr. Eugene Haanel, in a paper on the "Location and Examination of Magnetic Ore Deposits by Magnetometric Measurements" at the March, 1903, meeting of the Canadian Mining Institute and reprinted by the Department of Mines, Ottawa, Canada. These notes and drawings on the magnetometer are taken from the latter, with some additions from other reports of the Department of Mines, by permission of Dr. Haanel. Bound copies of Dr. Haanel's paper can be obtained from the Dept. of Mines, Ottawa, Can., for 50 cents each.

$$f=\frac{Pp}{d^2} \tag{1}$$

The lines of magnetic force radiate from each pole of a magnet, as may be seen by the position taken by iron filings sifted on a sheet of stiff paper laid over a magnet, or by the position taken by the needle of a small compass laid in the field. The needle of the latter will stand parallel to the line of force through it.

Normal Terrestrial Magnetic Field.—If a needle is free to swing in any direction it will place itself parallel to the line of force of the earth's magnetic field passing through it. The directions of these lines vary in different places. If points of equal declination are joined by lines, these are called *isogonic* lines. Similarly lines joining points giving the same vertical inclination to a needle, that is the same dip of the needle, are called *isoclinic* lines, and those joining points where the intensity of the magnetic attraction is equal are called *isodynamic* lines.

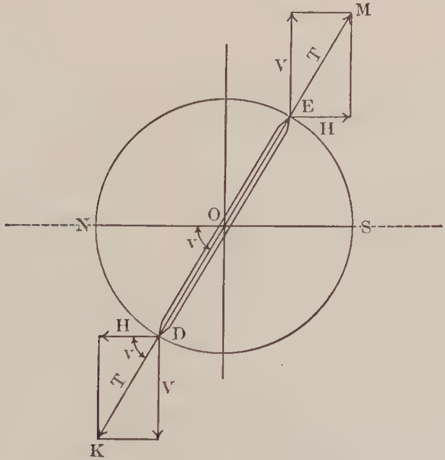

Fig. 192.—Attraction acting on a vertical needle.

Let Fig. 192 be in the plane of the magnetic meridian at the place of observation, and v be the angle which the needle DE makes with the horizon; then the needle is parallel to a line of force through O. The magnetic forces act with equal intensities on the north pole at D, and on the south pole at E, but in opposite directions, that is, $DK = EM$ and as the resultant equals zero, the needle is at rest. The observer is looking east at the figure.

The earth's attraction may be considered as resolved into a horizontal and a vertical component, then from the triangle of forces,

$$V = H \tan v \tag{2}$$

and

$$T = \sqrt{H^2 + V^2} = \frac{H}{\cos v} \tag{3}$$

Effect of a Magnet on a Compass Needle in a Normal Terrestrial Field.—The normal magnetic field of the earth may be considered as uniform for the comparatively small area of a magnetic survey, and the lines of force within this area as being parallel. The needle of a horizontal compass, set in the normal field, will come to rest on the magnetic meridian, N-S, see Fig. 193.

If under these conditions a deflecting magnet N'-S' is placed on an arm attached to the compass box, with its axis perpendicular to the magnetic meridian through O, in the same horizontal plane with the needle, and with its center at a distance d from the center of the compass, the needle will be deflected and come to rest parallel to the lines of force of the resultant field which is made up of the earth's field and the magnet's field. If the south pole of the deflecting magnet is toward the compass, the north end of the needle will be drawn toward it as in the figure.

To find an expression for the effect of the deflecting magnet let:

p = Strength of one pole of the compass needle,
P = Strength of one pole of the deflecting magnet,
$2l$ = Length of compass needle,
$2L$ = Length of deflecting magnet,

$2lp = m =$ Moment of the compass needle,[1]
$2LP = M =$ Moment of the deflecting magnet,[1]
$H =$ Intensity of the earth's horizontal field,
$d =$ Distance of center of magnet from pivot of needle.
$q =$ Intensity of the magnet's field at one end of the needle,
$F_h =$ Force with which earth's horizontal field acts on one pole of the needle,
$F_d =$ Force exerted by magnet on one pole of the needle.

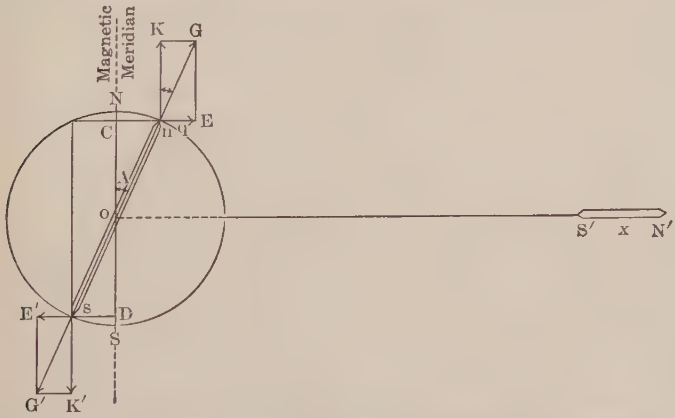

FIG. 193.—Tangent method of measuring horizontal attraction.

It is assumed that the force exerted by the magnet is the same at both ends of the needle and that the lines of force are parallel, but these assumptions are not strictly true and the effect of these two assumptions must be borne in mind in the subsequent discussion.

For the position of equilibrium, the moments about the center, O, are equal, hence:

$$F_h\, 2l \sin A = F_d\, 2l \cos A$$

Simplifying gives:

$$F_h \tan A = F_d \tag{4}$$

---

[1] The moment of a magnet is the product of the strength of one pole into the length of the magnet.

But

$$F_h = Hp \tag{5}$$

also F_d is the resultant of the action of the two poles of the magnet on one pole of the needle. Denoting attractions by minus and repulsions by plus signs, the attraction of the south pole of the magnet on the north pole of the needle is: $\frac{-Pp}{(d-L)^2}$ and the repulsion of the north pole of the magnet on the north pole of the needle is, $\frac{+Pp}{(d+L)^2}$. Assuming the line of attraction of these two forces to be parallel, gives,

$$F_d = \frac{-Pp}{(d-L)^2} + \frac{Pp}{(d+L)^2}$$

which reduces to

$$F_d = \frac{4PpLd}{d^4\left(1 - \frac{2L^2}{d^2} + \frac{L^4}{d^4}\right)}$$

The term $\frac{L^4}{d^4}$ is very small and may be neglected, giving:

$$F_d = \frac{2Mp}{d^3}\left(\frac{1}{1-\frac{2L^2}{d^2}}\right) \tag{6}$$

When d is large with respect to $2L$, the length of the magnet, the quantity in the brackets will not differ materially from 1, hence the last equation may be written:

$$F_d = \frac{2Mp}{d^3}. \tag{7}$$

Substituting equations (5) and (7) in equation (4) gives:

$$Hp \tan A = \frac{2Mp}{d^3} \tag{8}$$

or

$$H \tan A = \frac{2M}{d^3} \tag{9}$$

but $$H \tan A = q, \tag{10}$$

hence: $$qd^3 = 2M = a \text{ constant}. \tag{11}$$

If equations (5) and (6) are substituted in equation (4), the resulting equation will be:

$$M = \tfrac{1}{2} \tan A \, Hd^3 \left(1 - \frac{2L^2}{d^2}\right) \tag{12}$$

from which the moment of the magnet can be obtained in terms of H, or in absolute units when the value of H for the locality is known.

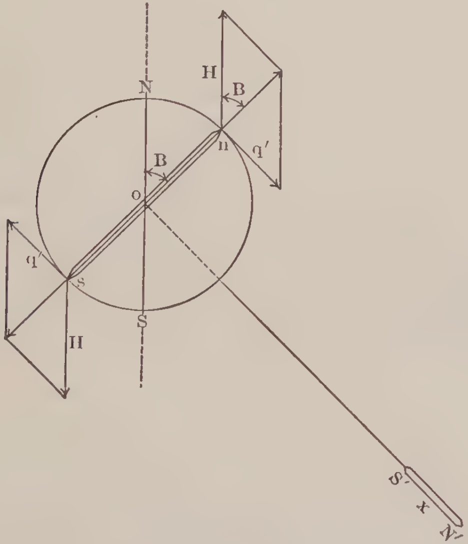

FIG. 194.—Sine method of measuring horizontal attraction.

This is the *Tangent Method* of determining the horizontal component of the magnetic forces at any point. It is evident that the results obtained are only approximately correct, since it was assumed that the strength of the field due to the magnet near the compass is the same at both the north and south points of the needle, which is not strictly true, and the error increases with the deflection of the needle. The method is valuable for some purposes, as will be discussed later, in spite of its errors.

The *Sine Method* affords a determination of the horizontal component of the magnetic forces at any point which is independent of the amount of deflection of the needle. The compass is equipped with an arm for holding a magnet, N'-S', the same as with the tangent method, the magnet is placed in position and the arm revolved until a position is found where the needle stands normal to the arm, see Fig. 194. In this position, both poles of the compass are at equal distances from the center of the magnet and occupy positions of equal strength.

The magnet is then removed and the angle through which the needle turns in returning to the magnetic meridian is a measure of the intensity of the horizontal magnetic force at the point of observation. Let B be the deflection angle, then,

$$q' = H \sin B \tag{13}$$

In the sine method, q' is constant and in the tangent method, q is nominally so, hence for different points in the field at which the value of H is different, the equations (10) and (13) may be written:

$$q = H \tan A = H_1 \tan A_1 \quad \text{or} \quad H_1 = H \frac{\tan A}{\tan A_1} \tag{14}$$

and

$$q' = H \sin B = H_1 \sin B_1 \quad \text{or} \quad H_1 = H \frac{\sin B}{\sin B_1} \tag{15}$$

From these equations the value of H_1 for any station can be found in terms of H, which may be the value of the horizontal component of the magnetic field at any one station and be used as the unit for the survey.

Thalén-Tiberg Magnetometer.—Robert Thalén devised an instrument for determining the horizontal forces on the principle just discussed; later, E. Tiberg's inclinator was combined with it into an instrument of convenient form, now known as the Thalén-Tiberg Magnetometer, and shown in Fig. 195 and 196.

This instrument consists principally of a compass 7.5 cm. in diameter, an arm on which is carried a magnet for determining the strength of the magnetic forces acting on the needle, and means for turning the compass into either a vertical or a horizontal position.

The compass has a needle 6 cm. long, that is carried by a double pivot with both top and bottom bearings, so that it may be used to measure angles in either the horizontal or the vertical position of the box. The needle differs from that of an ordinary dip compass, in that it is hung so that its center of gravity is below the pivot when used in a vertical position. The compass box is mounted on trunnions on the E. and W. line of the frame, and is provided with stops so that the compass is horizontal and vertical at the ends of the movement. The E. and W. line is marked zero to facilitate the measurement of vertical angles as will be shown in describing its application, but this change from the usual method of marking a compass causes no trouble as the needle is seldom used to measure bearings The compass has a screw for clamping the needle, a box level for use when used

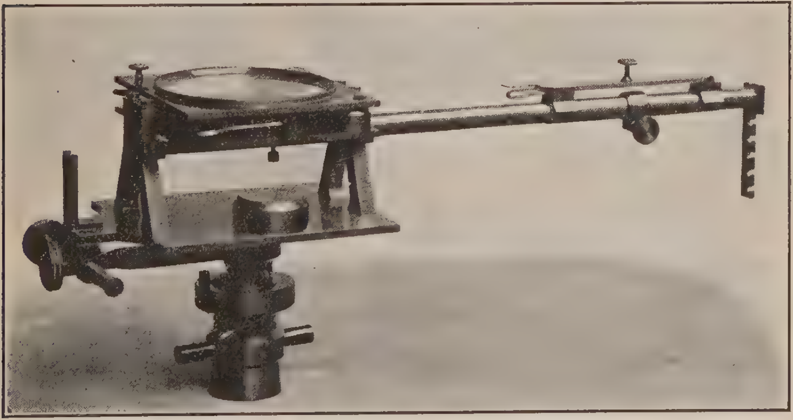

FIG. 195.—Thalén-Tiberg magnetometer.

in the hand, and a ring by which it can be suspended vertically when used for taking observations without the supporting tripod.

The frame is provided with another box level, clamp and tangent screws, sights for taking bearings, and a ball-and-socket joint for leveling.

The arm and the deflecting magnet are the characteristic features of the magnetometer. The arm is 22 cm. long, is fastened to the frame in a prolongation of the E. and W. line of the compass, and carries a slide on which a bar magnet, 1.1 by 0.2 by 10 cm., is held by a spring. The slide may be clamped in any position on the arm, and its position is indicated by the scale, whose zero is at the center of the compass. The bar magnet is in the plane in which the compass needle swings.

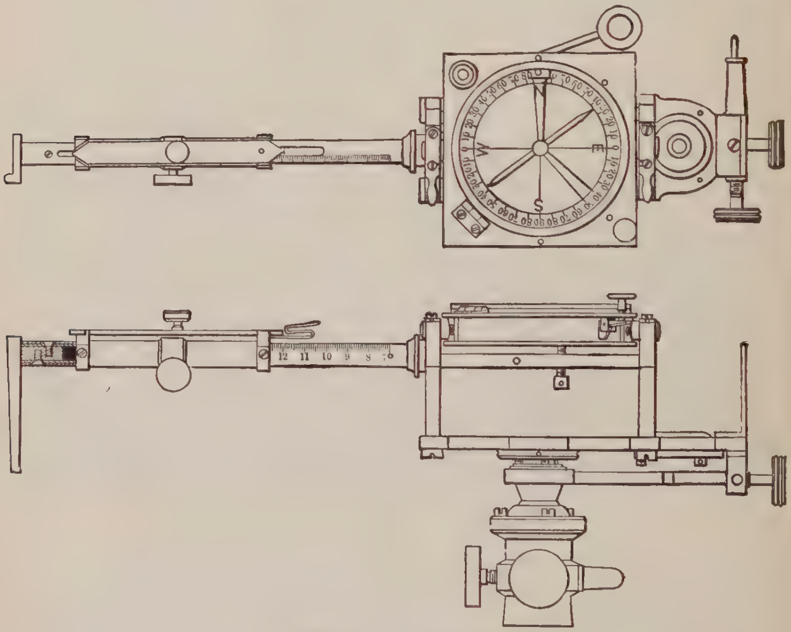

FIG. 196.—Thalén-Tiberg magnetometer.

Adjustments of the Magnetometer.—These consist of:

1. *Testing the Needle*, to see that the magnetic axis passes through the pivot, and that the pivot is in the center of the graduated circle. If eccentricities are shown, a true angle can be obtained by reading both ends of the needle and taking the mean.

2. *Adjusting the Box Bubble on the Frame*, by screws on the under side, if it is shown to be in error when the compass is reversed.

3. *Testing the Trunnions of the Compass Box*, with a stride level to see that they are in a horizontal plane when the axis of the instrument is vertical, if there is an error the low standard is raised by placing paper between it and the base.

4. *Testing the Stops* that limit the motion of the compass in its trunnions, so that the compass box shall be respectively horizontal and vertical in its two positions, as determined by a level and a plummet applied to the box.

5. *Balancing the Needle in the Normal Field*, by bringing the instrument into such a position that the needle reads 90°, then turning the compass vertically, and moving the weight on the south end of the needle until the needle stands at zero.

Measurement of the Horizontal Intensity of a Magnetic Field.—This may be found with the magnetometer by noting the angle of deflection of the compass needle produced by the deflecting magnet when it occupies a definite position on the arm. Either the tangent or the sine method may be used in this determination.

By the *Tangent Method*, the magnetometer is set level and rotated until the compass needle stands at the 90° marks, then the arm is normal to the magnetic meridian. The deflecting magnet is then placed in the slide, which is clamped in the desired position and the new position of the needle is read. The angle read may be called a_0 then the deflection angle will be $90° - a_o = A_o$.

In all observations, the compass should be tapped lightly, say with the rubber end of a pencil, to overcome the friction of the pivot on which the needle moves, and the deflecting magnet should be moved carefully in the vicinity of the needle so as not to set it in violent motion, thereby wasting time waiting for it to settle.

The relation of the deflection angle to the horizontal intensity is given by formula (10)

$$H \tan A_0 = q, \text{ then } H = \frac{q}{\tan A_o} = \frac{q}{\cot a_o} \qquad (16)$$

which gives the *horizontal intensity of the earth in terms of the intensity of the deflecting magnet* when set at a definite position on the arm. The slide is usually set so that angle A_o is 30° in the normal field.

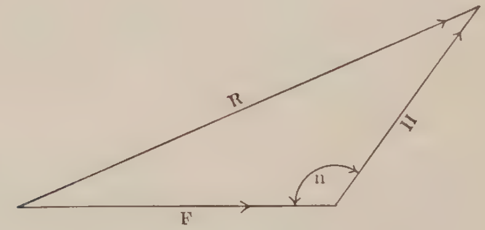

Fig. 197.—Diagram of horizontal forces.

If there are magnetic bodies in the vicinity, the terrestrial field will be disturbed and the compass needle will take a position along the horizontal resultant of the compound or disturbed field, when the deflecting magnet is not present.

Let F = the horizontal intensity of a magnetic body; R = the horizontal intensity of the compound or disturbed field; H = the intensity of the earth's horizontal field; then R will be the resultant of the other forces as shown by the triangle in Fig. 197, in which n equals the angle between the two forces. Then from trigonometry,

$$R = \sqrt{H^2 + F^2 - 2\,H\,F \cos n}, \qquad (17)$$

The value of R is found by measuring in a disturbed field, the angle A produced by the deflecting magnet in the same manner as used for the normal field, then

$$R=\frac{q}{\tan A}=\frac{q}{\cot a} \tag{18}$$

or from equation (16),

$$R=H\frac{\tan A_o}{\tan A}=H\frac{\cot a_o}{\cot a} \tag{19}$$

by which the intensity of the *horizontal component of the disturbed field* is given in terms of the *horizontal component of the normal terrestrial field,* for the same position of the deflecting magnet. This determination contains the errors inherent in the tangent method and so must be treated as approximate.

By the *Sine Method* the magnetometer is set level, the deflecting magnet is placed in the slide and the instrument rotated until the needle stands at 90°, that is, the arm is normal to the needle. Then the deflecting magnet is removed and the needle swings into the magnetic meridian. The new position of the needle is then read. The angle read may be called b_o, then the deflection angle produced by the magnet is $90° - b_o = B_o$.

From equation (13),

$$H=\frac{q'}{\sin B_o}=\frac{q'}{\cos b_o} \tag{20}$$

in which *the horizontal intensity of the earth is given in terms of the deflecting magnet.*

If R is the horizontal intensity of a disturbed field, and B is the deflection of the needle in this field, then,

$$R=\frac{q'}{\sin B}=\frac{q'}{\cos b} \tag{21}$$

and combining with (20) gives,

$$R=H\frac{\sin B_o}{\sin B}=H\frac{\cos b_o}{\cos b} \tag{22}$$

in which the *horizontal intensity of the disturbed field* is given in terms of the *horizontal intensity of the normal field.*

In order to standardize the magnetometer, it is necessary to determine the value of the horizontal component of the earth's normal magnetic field, H, in the vicinity to be examined, since this varies with each locality. The deflecting force of the deflecting magnet remains constant for long periods but the deflection angle A_o or B_o varies with the locality and must be found in order to determine H. This can be done by making a number of observations in different parts of the normal field surrounding the disturbed area to be examined. It is only by obtaining a large number of angles that do not differ that the observer can be sure that his observations have been made in a normal field.

A comparison of the two methods of measuring the deflection angle shows their respective applications.

The tangent method is convenient when approximate results are sufficient. The observation for the horizontal deflection is quickly made and when completed the instrument is in a proper position to be turned vertical for the observation of the vertical intensity, as is discussed later. But most important, a definite value for A will result from all intensities of R and q, as is seen from a consideration of equation (18), $\tan A = \frac{q}{R}$, for, whatever the values of the quantities q and R, the value of the ratio $\frac{q}{R}$ cannot fall outside of the range $+\infty$ and $-\infty$, which are the limits for the values of the tangents of angles.

The sine method gives accurate results but requires more time to take the horizontal deflections than is needed by the tangent method and then requires that the instrument be revolved before the vertical intensity can be measured. Further, from equation (21), $\sin B = \frac{q'}{R}$, it is evident, since the sines of angles are limited by the range $+1$ and -1, that the ratio $\frac{q'}{R}$ may have a value greater than 1 when $q' > R$, for which condition there will be no corresponding angle. At a station where this takes place, the needle cannot be made to take a position perpendicular to the axis of the magnet. This defect of the sine method can be overcome to some extent by increasing the distance d of the center of the deflecting magnet from the center of the compass, since q' decreases when d is increased. When q' diminishes, B_o also diminishes. Hence to measure small values of R, small values of B_o must be chosen by the observer and conversely larger values of R require greater values of B_o.

The calculation of the horizontal intensity R, in a disturbed field may be made with either equation (19) or (22), in which an arbitrary value may be given to the earth's force H, and then the solution will give relative values for the resultant force R. These arbitrary values indicate the center of local disturbance as well as if the actual values of H were used. Having the direction and intensity of both R and H, the construction of a triangle of forces at each place of observation will give the amount and direction of the force F, as in Fig. 197.

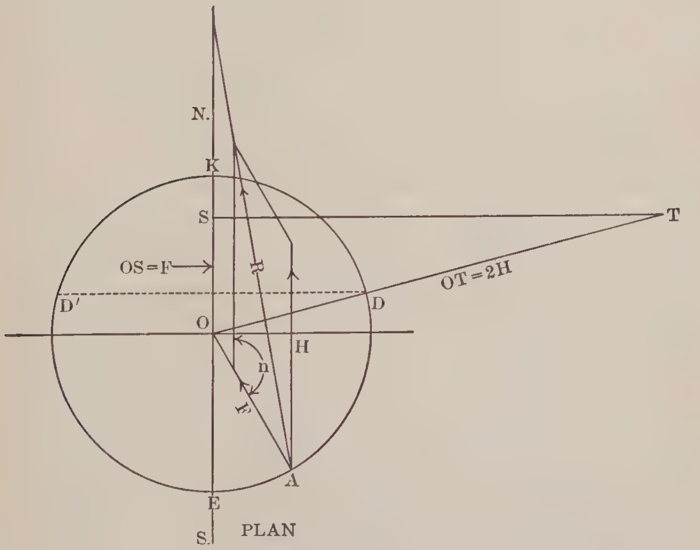

FIG. 198.—Horizontal forces acting in a disturbed field.

The solution of these equations is facilitated by tables of the ratios $\frac{sin\ B_o}{sin\ B}$ and $\frac{tan\ A_o}{tan\ A}$ as given in the samples below:[1]

TABLE OF VALUES OF $\frac{sin\ B_o}{sin\ B}$

	Values of B									
Values of B_o	1°	3°	5°	10°	15°	20°	30°	40°	60°	90°
10°	9.95	3.32	1.99	1.00	0.67	0.51	0.35	0.27	0.20	0.17
15°	14.83	4.94	2.97	1.49	1.00	0.76	0.52	0.40	0.30	0.26
20°	19.60	6.53	3.92	1.97	1.32	1.00	0.68	0.53	0.39	0.34
25°	24.21	8.07	4.85	2.43	1.63	1.24	0.84	0.66	0.49	0.42
30°	28.65	9.55	5.74	2.88	1.93	1.46	1.00	0.78	0.58	0.50

TABLE OF VALUES OF $\frac{tan\ A_o}{tan\ A}$

	Values of A									
Values of A_o	1°	3°	5°	10°	15°	20°	30°	40°	60°	90°
10°	10.10	3.36	2.01	1.00	0.66	0.48	0.30	0.21	0.10	0
15°	15.35	5.11	3.06	1.52	1.00	0.74	0.46	0.32	0.15	0
20°	20.85	6.94	4.16	2.06	1.36	1.00	0.63	0.43	0.21	0
25°	26.71	8.90	5.33	2.64	1.74	1.28	0.81	0.56	0.27	0
30°	33.08	11.02	6.60	3.27	2.15	1.59	1.00	0.69	0 33	0

The defects of the sine method, as commonly employed and described above, may be overcome by attaching another arm forming an angle of 30° with the regular arm and carrying the deflecting magnet in a movable slide. By this arrangement, the angle of deflection is kept constant and the influence q', of the deflecting magnet is varied to suit the strength of the field under investigation, by moving the deflecting magnet in or out on its arm and calculating the strength of the field from the position of the deflecing magnet. This is *Dahlblom's* modification of the sine method.[2]

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[1] In Dr. Haanel's treatise each table occupies 4½ pages, and values are given for each degree from 10° to 30° for A_o and B_o, and from 0° to 90° for A and B.

[2] Chapter VIII of Dr. Haanel's treatise gives a full description of this method.

Discussion of the Horizontal Forces of a Disturbed Terrestrial Field.—In a terrestrial field that is disturbed by a magnetic ore body, the horizontal force R is the resultant of the horizontal components of the earth's force, H, and of the magnetic force of the ore body, F. H remains constant in direction and in intensity, while F varies in both direction and in intensity, and depends on the horizontal distance of the point of observation from the pole of the ore body.

Assume that the pole of the ore body exhibiting north pole attraction, is situated vertically below O, see Fig. 198, and that the ore body extends vertically downward to such depth that the effect of the lower pole may be neglected.

Let H and F be the horizontal components of the field in both direction and intensity for a point A, then the diagonal R of the parallelogram constructed on these lines will represent the direction and intensity of the horizontal resultant of the field at A. At every point on a circle whose radius is O-A, the intensity of F will be constant but the force will have various directions. H is constant in both direction and intensity for all points. There are several points in such a field that are of special interest.

At E, the angle n is 180° and $\cos n = \cos 180° = -1$, hence equation (17) becomes

$$R = \sqrt{H^2 + F^2 - 2\ H\ F\ \cos\ n} = H + F \tag{23}$$

i.e., the resultant at this point equals the sum of the components.

At K, the angle n is 0° and $\cos n = \cos 0° = 1$, hence equation (17) becomes,

$$R = \sqrt{H^2 + F^2 - 2\ H\ F\ \cos\ n} = \pm\ (H - F) \tag{24}$$

i.e., the resultant at this point equals the difference of the components.

The total horizontal force R is therefore a maximum at E and a minimum at K and for these two points the angle of deflection is respectively, a minimum and a maximum. A line drawn through E, O and K constitutes the magnetic axis of the field. Between these points of $R_{\text{max.}}$ and $R_{\text{min.}}$. the value of R for intermediate points on the circumference assumes all intermediate values.

If in equation (17), R is put equal to H, then,

$$\cos\, n = \frac{F}{2H} \tag{25}$$

By constructing this angle at O, the points D and D' are found on the circumference where $R=H$, and at these points by equation (19), the angle of deflection is A_o, *i.e.*, the angle of deflection of the normal field; this is sometimes called the "neutral angle." So long as F is not greater than $2H$, there are two points in every circumference drawn within the field about O as a center, at which the angle of deflection is A_o. If a number of these points are found, the lines through them, called the "neutral line," will pass directly over the pole, *i.e.*, through O for at this point the force of the ore body is directly downward and is without a horizontal component, hence F is zero, the deflection is due only to H and is equal to A_o.

The point O on the neutral line is also a point on the line joining $R_{max.}$ and $R_{min.}$, hence *the pole of the ore body is directly below the point of intersection of these two lines*, when F is small as compared with H, which is the case with weakly magnetic bodies or one located at a distance from the surface.

At O, the force F is zero; on passing outward in the field this force becomes a maximum at some point, beyond which it diminishes until it is practically zero at the limits of the field. The intermediate values of F occur before reaching the maximum value and again after it is passed, and so will appear twice in passing out from the center, but the maximum will be found only once.

If $F_{max.} < H$, the free compass needle will point north at all points along the magnetic meridian. If $F_{max.} = H$, there will be one point on the meridian where $F - H = 0$ and the needle will indifferently occupy any position. If $F_{max.} > H$ but $< 2H$, there will be two points of indifference on the meridian, one lying within the circumference for the maximum and the other beyond it; after passing the first point of indifference the needle reverses and points southerly until the second point of indifference is reached when it reverses again and points northerly once more. In this case one neutral line will divide the field into areas of maximum and minimum horizontal intensities.

When $F_{max.} > 2H$, two neutral lines will be found between the two indifferent points, one a closed curve passing through O which is the "false neutral line," and a second, an open curve lying beyond the former to the north which is the "true neutral line."

Vertical Intensity of a Disturbed Terrestrial Field.—A magnetic needle hung so that it can move in any direction will place itself parallel to a line of magnetic force; one pole of the needle will point downward and make an angle v with the horizontal. In this position, the horizontal and vertical components of the magnetic force acting on the needle are in the relation, $V = H \tan v$ (2). The vertical plane through the needle will be the magnetic meridian. This is the condition under which the dip compass operates.

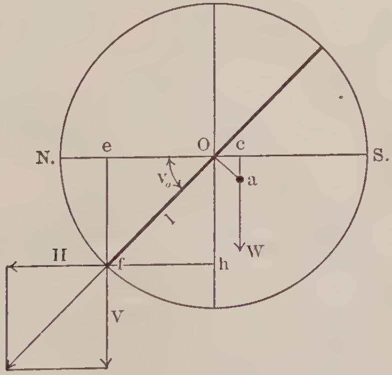

FIG. 199.—Forces acting on an inclinator.

In the magnetometer, the center of gravity of the needle is so placed that it is a little below the pivot when it swings in a vertical plane, and the position of the needle is influenced by gravity as well as by the magnetic forces, which is the peculiarity of the Tiberg "inclinator."

Fig. 199 represents a vertical plane through the needle of the magnetometer when used as an "inclinator." Let W be the weight of the needle, considered to be concentrated at its center of gravity, a, at a distance d' from O; H and V be the horizontal and vertical components acting on the needle; $l = O\text{-}f$ be one-half the length of the needle; v be the angle made by the needle with the horizontal; and p be the strength of one pole, f, of the needle. The observer is looking east at the figure.

Then taking moments about O, remembering that H and V act on both ends of the needle, gives

$$Vp\ 2l \cos v_o = Hp\ 2l \sin v_o + Wd' \sin v_o,$$

hence
$$V = \left(H + \frac{Wd'}{2pl}\right) \tan v_o = \left(H + \frac{Wd'}{m}\right) \tan v_o \qquad (26)$$

If the vertical plane in which the needle swings makes an angle, C, with the magnetic meridian, the horizontal component will be $H \cos C$, and the last equation becomes

$$V = \left(H \cos C + \frac{Wd'}{m}\right) \tan v_1 \qquad (27)$$

With the inclinator, the observations are made in a plane perpendicular to the magnetic meridian, *i.e.*, $C = 90°$, hence $\cos C = O$, and the value of the vertical intensity becomes

$$V = \frac{Wd'}{m} \tan v_2 \qquad (28)$$

in which $\frac{Wd'}{m}$ is a constant and can be replaced by the letter K, giving:

$$V = K \tan v_2 \qquad (29)$$

In a field disturbed by the presence of a magnetic ore deposit, the horizontal and vertical forces acting on the needle are the resultants of the horizontal and vertical components of the earth's field and the field of the ore deposit. Thus the horizontal force is the resultant, R, derived from H from the earth and F from the ore deposit, and the vertical force is the resultant, derived from V from the earth, and $\pm G$ from the ore deposit. In the latter, + signifies attraction for the north pole and − for the south pole.

In the presence of an ore deposit, the forces acting on the needle are R and G, as V has been balanced by a small weight on the south end of the needle, then by a similar deduction to that used for equation (26), when the inclinator is in the plane of the magnetic meridian, the vertical attraction of the deposit is

$$\pm G = (R+K) \tan v'_o \qquad (30)$$

When the inclinator makes an angle C with the magnetic meridian, then:

$$\pm G = (R \cos C + K) \tan v'_1 \qquad (31)$$

When $C = 90°$ and the inclinator is normal to the magnetic meridian, then:

$$\pm G = K \tan v'_2 \qquad (32)$$

Value of K.—In the expression $K = \frac{Wd'}{m}$, the weight of the needle, W, and the moment of the needle, m, can be determined. The latter, however, decreases with time, but the distance d' cannot be accurately ascertained, hence the value of K cannot be found directly and is best determined by experiment. Several methods are available, but as a preliminary to any of them, the needle must be balanced for the vertical attraction of the earth by a weight on the south end.

First Method.—In a strong magnetic field, set the magnetometer horizontal and revolve it until the needle is parallel to the trunnions, then turn the compass box vertical, when the needle will swing in the plane of the magnetic meridian. If R = the horizontal intensity and G = the vertical intensity of the field, then equation (30) will become $G = (R+K) \tan v'_o$ (a). Next set the compass horizontal, turn the magnetometer until the needle is perpendicular to the trunnions, then turn the compass box vertical when the needle will swing normal to the magnetic meridian, let the second reading be v'_2. In this position, R does not affect the needle and from equation (32), $G = K \tan v'_2$ (*b*). Combining (*a*) and (*b*) gives:

$$K = \frac{\tan v'_o}{\tan v'_2 - \tan v'_o} R \qquad (33)$$

in which R can be found by the sine method from equation (22).

Second Method.—In the normal field, a strong magnet is suspended under the magnetometer with the south pole upward, a reading is taken with the inclinator perpendicular to the magnetic meridian, arm to east, hence $C = 90°$, which substituted in (32), gives $G = K \tan v'_2$ (*c*). A second reading is taken with the arm turned south, while the inclinator is vertical, thus causing the north end of the needle to be at the south, the inclinator is now 180° from the magnetic meridian, making $C = 180°$, and $\cos C = -1$. The horizontal effect of the magnet is zero, hence the horizontal force acting on the needle is due entirely to the earth and $R = H$; the vertical force of the earth is balanced leaving only G to act on the needle, then from equation (31), $G = (K - H) \tan v'_3$ (*d*) and combining (*c*) and (*d*), gives:

$$K (\tan v'_3 - \tan v'_2) = H \tan v'_3, \text{ hence } K = \frac{\tan v'_3}{\tan v'_3 - \tan v'_2} H \qquad (34)$$

A number of determinations of K are made with the magnet at different distances below the compass and the mean is used for the working value.

Third Method.—In the normal field, the magnetometer is set horizontal with the arm to the east side, and with the needle on the 90° line; the compass box is turned vertically, the deflecting magnet is placed in its slide with the north pole toward the north end of the needle, and then is cautiously moved toward the compass until the needle stands approximately vertical as in Fig. 200, where he observer is looking south. $H = 0$, as the needle swings in a plane perpendicular to the magnetic meridian.

Let F_d equal the force exerted by the deflecting magnet on one pole of the needle whose strength is p. Then the moment about O are, $Wd'=F_d 2l$, but from equation (7), $F_d=\frac{2Mp}{d^3}$ hence $Wd'=\frac{4Mpl}{d^3}=\frac{2Mm}{d^3}$ and from equation (11), $\frac{2M}{d^3}=q$, hence $Wd'=mq$ or $q=\frac{Wd'}{m}$ but the second term also equals K, by definition, see also equations (28) and (29), hence $K=q$. Then, the value of q can be determined with the unchanged position of the deflecting magnet by the sine method, by equation (13), giving $K=q'=$

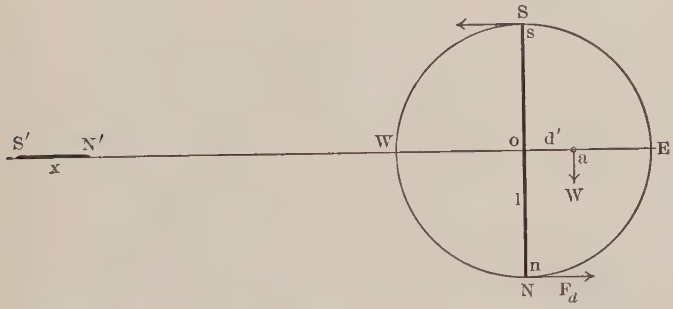

FIG. 200.—Determination of "K" by the third method.

$H \sin B_o$. From the last equation K can only be determined in the normal field, when $K \leq H$. If $K > H$, it must be determined in a disturbed field south of the neutral line.

In all three of the methods the value of K is obtained in terms of H and therefore G as determined by the inclinator is also expressed in terms of H.

The sensitiveness of the inclinator increases with a decrease of K, and K varies directly as W and d', and inversely as $2pl$. Sensitiveness is best obtained by making d' small and both p and l as great as possible. In the Swedish instruments, the value of K varies from 0.5 H to 1.5 H.

Method of making Observations with the Inclinator.—The magnetometer is set up at the place of observation, as described for the tangent method, with the needle reading 90°; the compass box is turned vertically; and the angle of inclination v, is read from the north end of the needle. To overcome the friction of the needle, the box is tapped lightly or the suspension ring is allowed to drop against the case to jar it slightly. For preliminary observations, the inclinator can be removed from its frame, and used in a similar way by being held in the hand, permitting more rapid although less accurate work.

Investigation of Magnetic Ore Deposits.—A preliminary investigation of the field is made with a vertical needle and the points of maximum inclination are located, using either the dip compass or the inclinator.

A line joining the points of maximum dip gives the strike of the deposit. This line is prolonged in each direction until its ends are beyond the disturbed field. On this line stakes are set at the desired intervals, say 30 ft., and perpendicular lines are run from these to the side limits of the disturbed field and points for observation marked at the desired intervals along these branch lines; thus the field is divided into squares. The stakes may be identified by giving a letter to each row and by numbering the stakes in the rows. The sights of the magnetometer may be used in laying out these lines normal to the base line.

A plot is made of the field showing the squares laid out on the ground, and the principal topographic and artificial features. Contour lines are especially important in interpreting the results of the magnetic measurements, as the shape of the ground influences the distance of the magnetometer from the ore bodies. A scale of 1 in. = 60 ft. is convenient, then the 30-foot squares are $\frac{1}{2}$ in. on a side on the plot.

Two adjustments of the magmetometer are invariably made in the vicinity of the ore bodies, but beyond its magnetic influence. First, the magnetometer is set with the compass horizontal and is rotated until the needle points to 90°, *i.e.*, at a right angle to the axis of the compass box. The compass is then turned vertical and the weight on the needle adjusted until it stands in a horizontal position. Second, the compass is again turned horizontal and the needle allowed to swing back to 90°, and at right angles to the arm. The deflecting magnet is placed in its slide and moved along the arm until the needle reads, say 60° on the circular graduations, that is, it has been deflected 30°, and then the slide is clamped. Conditions vary the amount of deflection used, but 30° is usually a satisfactory amount for the deflection in the normal field.

The magnetometer is now set up at each stake in succession and the values of the horizontal and vertical angles are read and noted. South pole attraction being noted by a minus sign in front of the angle. In cases of rapid change in the magnetic force, it will be necessary to take intermediate observations.

For a complete investigation of the field, the angle which the horizontal resultant, R, makes with the survey line should be found, by placing the sights of the magnetometer on the line and reading the angle made by the needle with the fixed line. This may be called, D. The mean value of D_o observed beyond the disturbed field gives the mean direction of the magnetic meridian of the district.

The value of the angles, A or B, v and D, are noted on the plots in their respective places. A separate plot is usually made of each of the quantities, viz.: horizontal intensity, vertical intensity, and direction of the resultant. If the points of equal intensity are joined on each of the first two charts, a system of isodynamic lines is obtained in each, and if the points of equal declination are joined on the third chart, a system of isogonic lines is obtained.

On the map of vertical intensities, the curves are drawn through the zero points and through points of 10° higher and lower dip. The positive areas are often tinted blue and the negative are tinted yellow. One wash is used between 0° and 10°, two washes between 10° and 20°, and so on, both above and below zero, thus increasing the density of the tint with an increase in the intensity.

On the map of horizontal intensities the neutral line is drawn where the horizontal intensity is the same as in the normal area, often 30° is used, and the isodynamic lines are drawn 5° apart.

Areas showing deflections above the normal are often tinted green and those below are tinted pink; the depth of the tints increasing with each increase of the intensity.

Charts of an Ideal Magnetic Field.—In order to investigate the forces in a magnetic field, let an ideal bar magnet 100 m. in length be placed at an inclination of 53° in an east and west direction, having its south pole upward and 30 m. below the plane of observation, and having a pole strength of 5,400,000 C.G.S. units. *H* is assumed as .18 C.G.S. units.

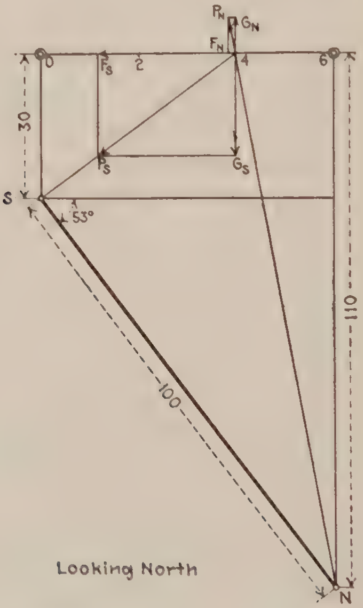

FIG. 201.—Vertical section through ideal bar magnet.

Let Fig. 201 be an east and west vertical plane through the magnet. Then at a point, 4 (40 m. to the right of 0), the intensities of the two poles will be $P_s = \frac{P}{d^2} = \frac{5,400,000}{(5,000 \text{ cm.})^2} = 0.216$ units in strength, and $P_n = \frac{P}{d_s} = \frac{5{,}400{,}000}{(11{,}200 \text{ cm.})^2} = 0.043$ units in strength, and the lines 4-S and 4-N indicate the direction of these forces.

The forces P_s may be resolved into horizontal and vertical forces F_s and G_s and the force P_n into F_n and G_n by constructing the parallelogram of forces as shown. These components of intensity of both poles may be found similarly for other points and if plotted as ordinates, enable the curves of the magnetic intensity to be drawn, Fig. 202. Thus for point 4 the value of F_s and F_n are the ordinates of the curves of horizontal intensity of the upper and lower poles respectively, and G_s and G_n are the ordinates of the curve of the vertical intensities of the upper and lower poles respectively. The directions in which the forces act are indicated by the arrows in the chart.

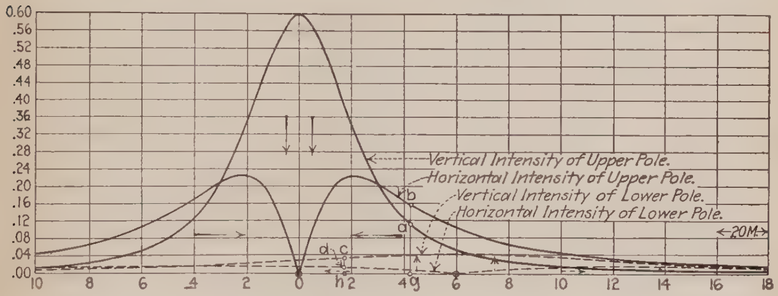

FIG. 202.—Curves of magnetic intensity due to the ideal bar magnet.

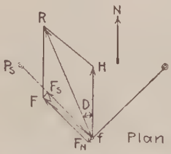

FIG. 203.—Diagram of horizontal forces at any point, as f which is midway between P_s and P_n and 30 m. south of them; see Fig. 204.

The intensities of the forces at any point depend on the distance of the point from the pole, so at points at the same distances from 0 and 6, which are the vertical projections of the poles, the magnetic forces are the same as for point 4.

Suppose it is required to find the intensity of the magnetic forces at *f*, in Fig. 203. The point is at a distance, f-P_s and f-P_n from the vertical projection of the two poles. The distance f-P_s laid off from 0 on the chart, locating point *g*, then the ordinates is *g-a* and *g-b* give the vertical and horizontal intensity of the upper pole, and similarly the distance f-P_n is laid off from 6 at the point *h*, then the ordinates *h-c* and *h-d* give the influence of the lower pole.

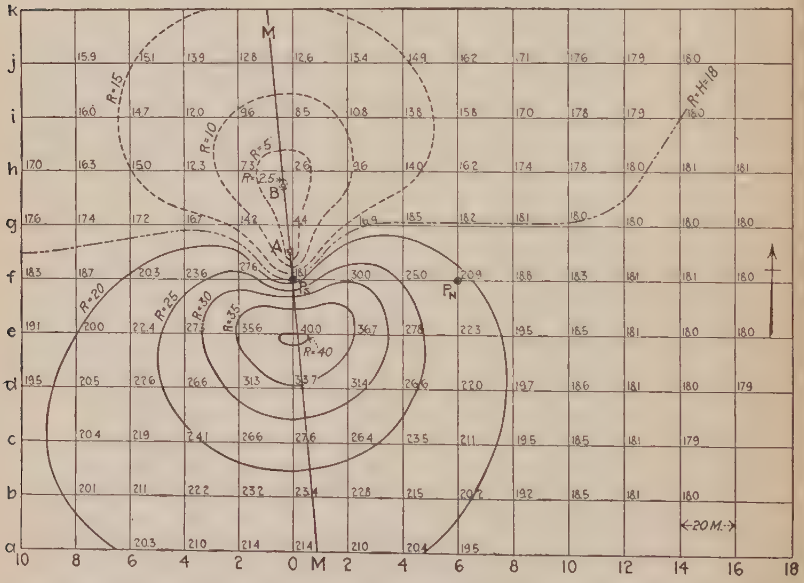

Fig. 204.—Chart of the horizontal intensity, *R*, of the ideal magnetic field.

The vertical forces at *f* from the two ends act in opposite directions, and hence the net vertical force is their difference, or *g-a* — *h-c*. The horizontal forces act in the directions of the poles from *f*, the intensities are given by the ordinates of the curves;

g-b is laid off from f toward P_s as F_s, also h-d is laid off from f as F_n, then the resultant F is the direction and the intensity of the horizontal force at f of the magnet. The horizontal component of the earth's field is H, assumed as .18 units and is laid off from f to the north. By drawing a parallelogram of forces on H and F the resultant horizontal intensity R of the field is found and D is the angle which it makes with the magnetic meridian.

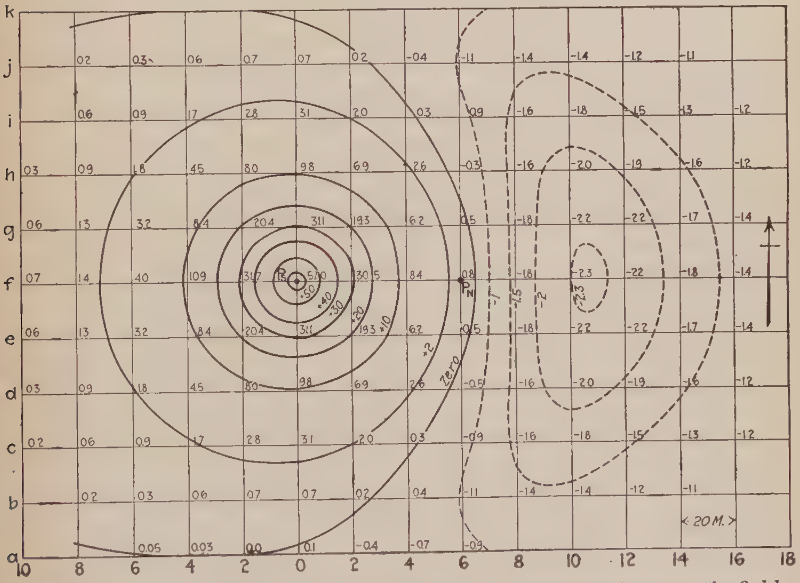

Fig. 205.—Chart of the vertical intensity, G, of the ideal magnetic field.

A chart of the *horizontal intensity* of the ideal disturbed field, as in Fig. 204, may be drawn by determining the value of R from a construction similar to Fig. 203, for numerous points on a plan and then drawing lines through points of equal values of the horizontal resultant R, these are isodynamic lines of horizontal intensity. The neutral line, where $R = H = 18$, or $A = A_o$, is shown as a dot-and-dash line, and passes through P_s the projection of the upper pole, and divides the area of minimum attraction where $R < H$, from the area of maximum attraction where $R > H$. The line M-M drawn through the points of maximum and minimum horizontal intensity is the magnetic meridian of the field and the neutral line intercepts it at the point P_s. Points A and B are points of indifference where the needle will point in any direction. On the charts H is taken as 100 times the $G.C.S.$ unit.

A chart of the *vertical intensity* of the ideal disturbed field, Fig. 205, may be drawn by combining the values of G for the two poles of the magnet as given in Fig. 202 for numerous points on the plan, and then drawing lines through the points of equal vertical intensity, these are isodynamic lines of vertical intensity.

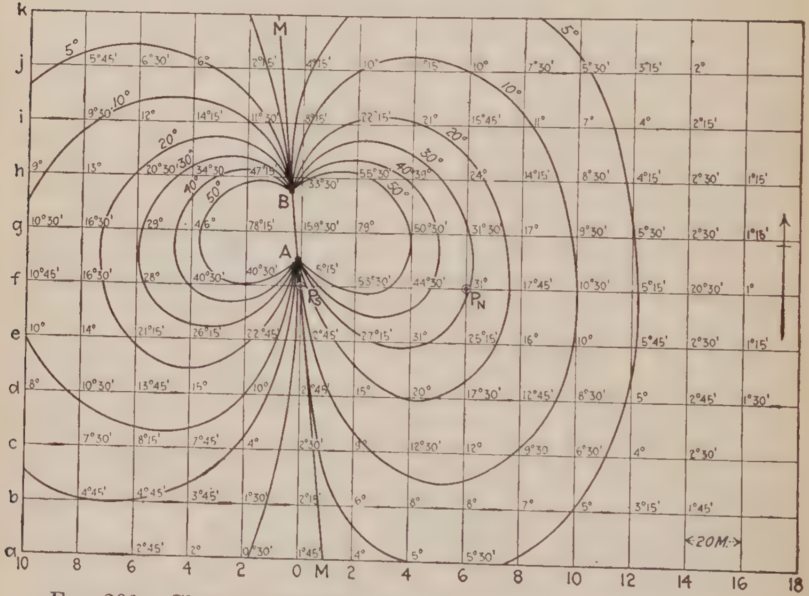

FIG. 206.—Chart of the declination, D, of the ideal magnetic field.

The point of maximum vertical intensity is directly over the upper pole and the magnetic body dips down toward the area of maximum negative attraction.

A chart of the *declination* of the compass needle in the ideal disturbed field may be drawn, by noting on a plan, Fig. 206, the values of the angle D obtained from the force diagrams used in determining R, see Fig. 203, and then drawing lines through the points of equal declination, these are isogonic lines. The magnetic axis of the deposit is shown by the line M-M.

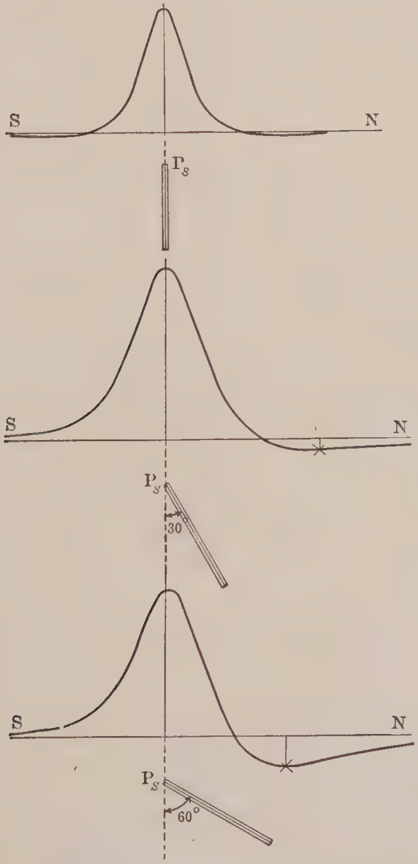

Fig. 207.—Profile curves of vertical attraction, produced by magnets.

In the ideal case, the curves, Fig. 202, were constructed first from the known intensity of the magnet. In investigating an area, the isodynamic charts are first made from the data collected in the field, and then the vertical sections showing the value of G are constructed along various lines across the field.

The vertical intensity of G, for a field containing only one ore deposit, is a maximum directly over the pole of the deposit; decreases rapidly at first, then more slowly; becomes a weak negative and finally returns to zero at a greater distance. This is shown for an ideal magnet in Fig. 207. The effect of the inclination of the magnet on the profile is shown in the last two curves in the figure, where the decrease in the dip causes the curves to become more unsymmetrical and the negative attraction more pronounced. A flattening of the crest of the curve, correspond-

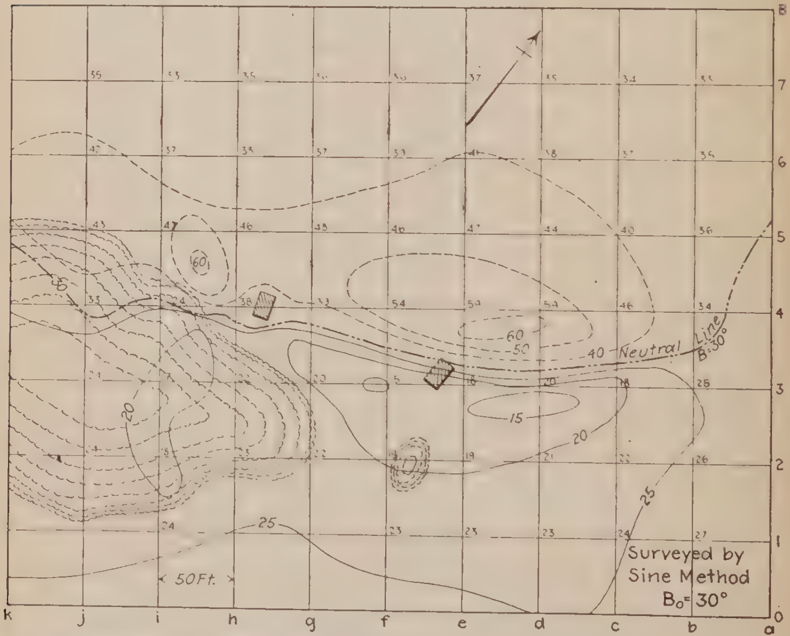

FIG. 208.—Plot of the horizontal intensity due to an ore deposit in terms of deflection angle, B.

ing to a slow decrease from the maximum, indicates that the deposit is at a great depth, or that it is very extensive and lies at a flat angle, so that the influence of the lower pole is not marked.

Charts of Magnetic Ore Deposits.—A lens-shaped deposit of magnetite buried about ten feet under a fairly level surface was

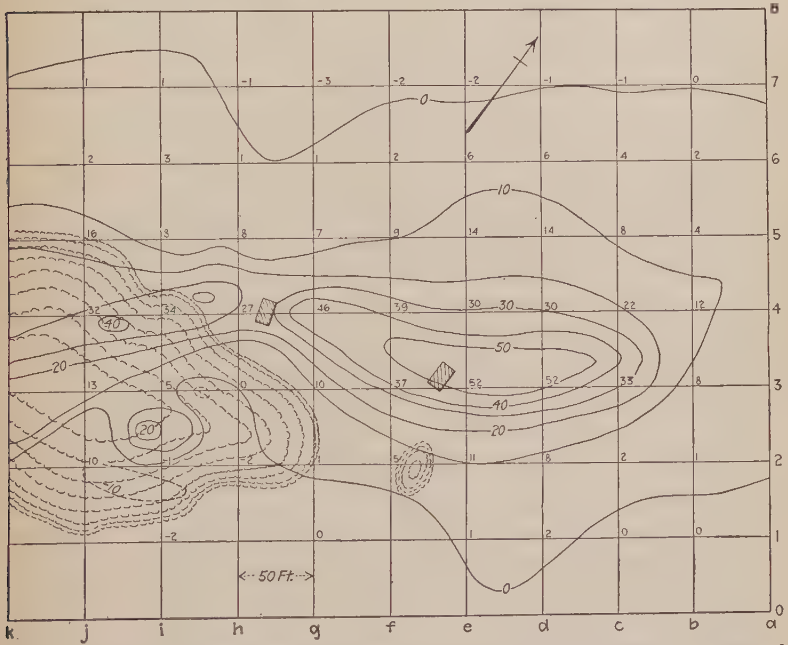

FIG. 209.—Plot of the vertical intensity due to an ore deposit, in terms of the vertical angles read with the inclinator.

surveyed and the resulting plots are shown in Fig. 208 and 209. In the first plot, the horizontal intensities were determined by the sine method, using $B_o = 30°$, and the figure gives the value of B, at the points of observation. The neutral line passes through points where $B = 30°$. The magnetic axis of this deposit is a line joining the areas of maximum and minimum intensity, and its intersection with the neutral line indicates that the pole is near the point *d*-3.

The second plot shows the distribution of the vertical intensities. The pole lies under the point of maximum intensity which is near *d*-3. The dip of the deposit is in the direction of the stronger magnetic attraction and hence in a northerly direction. The strike is in the direction of the longest axis of the curves of maximum intensity, hence nearly east and west. The curves are regular and elliptical which indicates a concentrated mass of regular shape.

The influence of the rock dump, containing some ore at the left side of both figures, causes new curves in this portion of the field, somewhat resembling those formed by an ore deposit.

Discussion of Magnetic Ore Charts.—The map of the vertical intensity gives the most information. The interpretation of these charts may be summarized briefly as: the maximum positive reading is over the upper pole of the ore body; long, narrow, elliptical curves indicate regular bodies; the strike is along the long axis of the curves of maximum intensity; irregular curves are due to irregular masses, multiple ore bodies, or presence of artificial magnetic bodies; the dip of the ore body is toward the side where the magnetic intensity decreases more slowly, *i.e.*, where the isodynamic curves are farthest part.

The effect of the lower pole is shown in the negative area surrounding the area of positive vertical intensity of every magnetic deposit. If the ore descends to a great depth, the attraction of the lower pole is feeble. The curves of high positive vertical intensity will generally represent the approximate shape of the outcrop of the ore body. The position of outcrops and openings aid in showing the size of the deposit and which curve conforms to the outline of the ore.

When a deposit is deeply covered the vertical intensity indicates its presence, but few conclusions can be drawn as to its size or shape, as the maximum intensity is low. Low grade disseminated deposits give complicated maps which must be considered carefully to distinguish them from those resulting from large deep-lying deposits. If the ground slopes rapidly, and the ore dips into the hill, the positive curves over the deposit are closer together than they would be if the ground were level, as the instrument is at a greater distance from the ore. If the hill is very steep, observations made beyond the outcrop may be taken below the pole and the north end of the needle be drawn upward, giving a negative reading.

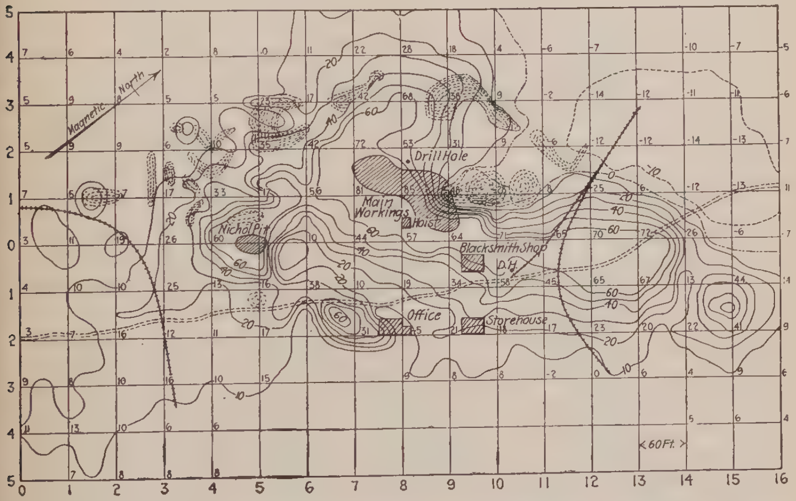

FIG. 210.—Plot of the vertical intensity at the Belmont Iron Mines, County of Peterboro, Ontario, Can., in terms of angle, v.

The most important thing that is shown by a map of horizontal intensity is the location of the upper pole. With a single deposit, a line from the point of maximum to the point of minimum horizontal intensity intersects the neutral line over the pole; if, however, there are several ore bodies, or one of irregular shape, the map is complicated and little information can be obtained from the map of horizontal intensities.

At the *Belmont Iron Mines*[1] the conditions for the magnetic survey were very favorable, as the ground was comparatively level and free from obstacles, thus giving isodynamic curves that were free from complications due to uneven ground, and which allowed of accurate interpretation. The deposit had been opened by two pits, and dipped slightly to the north.

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[1] Abstract of "Report of Superintendent of Mines," 1906, Dept. of Mines, Ottawa, Canada.

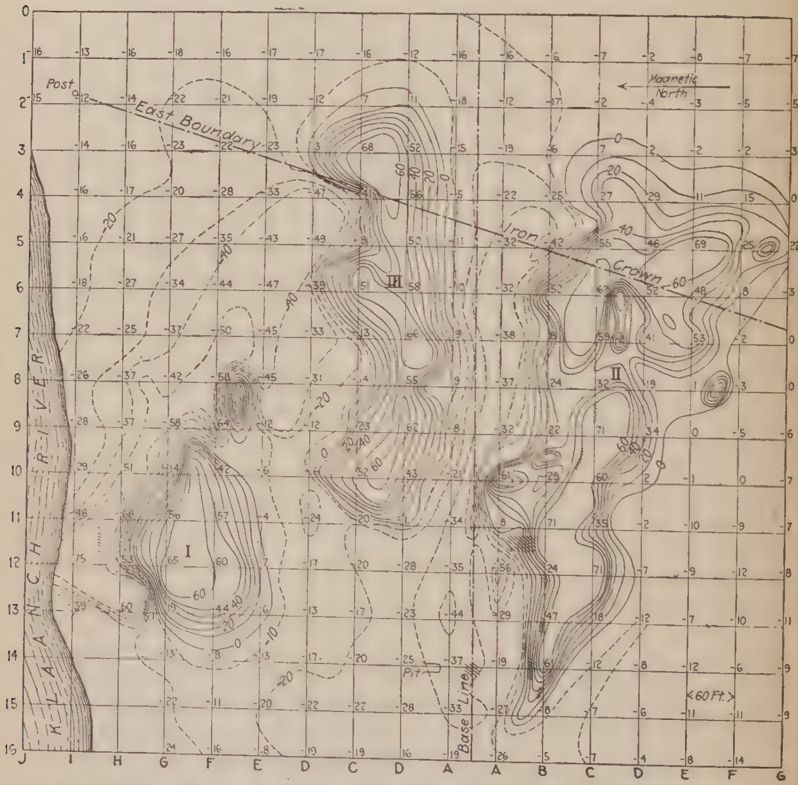

FIG. 211.—Plot of the vertical intensity at the Iron Crown Claim, Klaanch River, Vancouver Is., B. C., in terms of angle, v.

A base-line running NE. and SW. was laid out about 1000 ft. long and marked at 30-foot intervals, perpendicular lines 300 ft. long were run on each side and staked every 30 ft. The vertical intensity was very regular, as shown in the plot, Fig. 210, and the main portion of the outcrop probably lies within the 60° curve. The negative area shows a very feeble attraction which indicates that the south pole of the ore body is at a considerable depth. A few holes drilled on the property at a later date seemed to confirm these deductions.

At the *Iron Crown Claim*,[1] an exposure of magnetite extends along the face of the river bank, which is 80 to 100 ft. high, and the magnetite at some points stands in cliffs 25 to 30 ft. high. The deposit dips slightly into the bank. The sloping ground brought the instrument on the side of the deposit toward the river, below the upper pole and so caused the negative readings close to the positive area and accounts for the negative area over the outcrops, see Fig. 211.

Deposit *I* is estimated to be 160 ft. long, which is the length of the 60° curve and about 100 ft. wide at the west end, this being the width of the 60° curve at this point with 30 ft. added to take in the outcrops, thus offsetting the effect of the sloping ground, which caused the negative area to draw up close to the maximum positive area.

Deposit *II* is the most important and probably consists of two and possibly three lenses, not counting the small pocket in the south part. The largest lens is estimated to be 380 ft. long and a general width of about 60 ft.

Deposit *III* is entirely covered with soil, but the magnetic curves indicate that it is about 480 ft. long, and lies practically parallel to the others.

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[1] Abstract of "Iron Ore Deposits of Vancouver Island," by E. Lindeman, Bull. 47, Department of Mines, Canada.

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